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RESEARCH MEMORANDUM

PRELIMINARY EVALUATION OF TURBINE PERFORMANCE WITH VARIABLE-AREA TURBINE NOZZLES IN A TURBOJET ENGINE

By Carl E. Campbell and Henry J. Welna

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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PRELIMINARY EVALUATION OF TURBINE PERFORMANCE WITH VARIABLE-AREA TURBINE NOZZLES IN A TURBOJET ENGINE

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SUMMARY

The performance of a two-stage turbine with variable-area first-stage turbine nozzles was determined in the NACA Lewis altitude wind tunnel over a range of simulated altitudes from 15,000 to 44,000 feet and engine speeds from 50 to 100 percent of rated speed. The variable-area turbine nozzles used in this investigation were primarily a test device for compressor research purposes and were not necessarily of optimum aerodynamic design. The results of this investigation are indicative of effects of turbine-nozzle-area variation on turbine performance within the operating range allowed by the engine. The variable-area turbine nozzles were found to be mechanically reliable and to have negligible leakage losses. Increasing the turbine-nozzle-throat area from 1.15 to 1.67 square feet increased the corrected turbine gas flow or effective turbine nozzle area about 10 percent. At a given corrected turbine speed and turbine pressure ratio, changing the turbine nozzle area from 1.30 to 1.67 square feet lowered the turbine efficiency 3 or 4 percent. The effect of increasing the turbine nozzle area from 1.15 to 1.67 square feet (decreasing the turning angle about $7\frac{1}{2}^{\circ}$) would be to lower the turbine efficiency about 5 or 6 percent.

INTRODUCTION

Analyses such as that given in reference 1 indicate the performance and operational advantages to be gained by utilization of variable-area turbine nozzles in turbojet engines. When combined with a proper speed control, the variable turbine nozzle can greatly increase the thrust capability of supersonic turbojet engines because of increased flexibility in matching of the compressor and turbine over a wide range of flight conditions. Furthermore, potential improvements in specific fuel consumption, particularly at thrust values below rated thrust, are possible for engines equipped with both variable-area turbine nozzles and variable-area exhaust nozzles (reference 1). In both these analyses, it was assumed that turbine efficiency was not affected by changes in the area or angle of the turbine nozzles. However, aside from analytical treatment of the problem, there exists at the present time a lack of

experimental data on the performance of variable-area turbine nozzles operating as integral components of full-scale turbojet engines. Complexity and mechanical reliability have been the main deterrent factors in obtaining experimental data and in the utilization of variable turbine nozzles in present turbojet engine designs.

During a study of the surge characteristics of a turbojet engine fitted with variable-area first-stage turbine nozzles in the NACA Lewis altitude wind tunnel, it was possible to obtain some preliminary data on the effect of these nozzles on the performance of the two-stage turbine. The effect of the variable-area turbine nozzles on the efficiency and gas flow characteristics of the turbine are presented herein. The variable-area turbine nozzles investigated in this study were intended primarily to provide a variable compressor pressure ratio independent of engine speed and turbine-inlet temperature for compressor research purposes; therefore, the aerodynamic design of the nozzles was not necessarily optimum. Furthermore, the turbine rotors and the second-stage stator were designed for fixed-area first-stage nozzles. The experimental results obtained in this investigation, therefore, do not represent the best turbine performance obtainable with variable-area turbine nozzles, but serve instead as a preliminary indicator of general performance and mechanical problems. 2618

Corrected turbine gas flow and turbine efficiency are presented as functions of corrected turbine speed and turbine pressure ratio to show the effects of turbine nozzle area and nozzle angle on turbine performance. The turbine efficiency obtained with the original fixed turbine nozzles is compared with the turbine efficiency obtained with the variable turbine nozzles at a position corresponding to approximately the same throat area and turning angle. All turbine performance data obtained with the variable turbine nozzles are presented in numerical form in table I.

INSTALLATION AND INSTRUMENTATION

Engine

The engine was mounted on a wing section which extended across the 20-foot-diameter test section of the altitude wind tunnel (fig. 1). Dry refrigerated air was supplied to the engine from the tunnel make-up air system through a duct connected to the engine inlet. Manually controlled butterfly valves in this duct were used to adjust the total pressure of the refrigerated air at the engine inlet to correspond to the desired flight condition, while the static pressure in the tunnel test section was maintained to correspond to the desired altitude. A slip joint with a frictionless seal in the duct permitted the measurement of thrust and installation drag with the tunnel scales.

The engine used in this investigation was a J40-WE-6, which had a sea-level rating of 7500 pounds of jet thrust at an engine speed of 7260 rpm and a turbine-inlet temperature of 1425° F. At this rating, the compressor pressure ratio was about 5.0 and the engine air flow was 140 pounds per second. A cross-section of the engine is presented in figure 2 showing the main components of the engine which included an eleven-stage axial-flow compressor, a single-annulus basket-type combustor, a two-stage turbine, and a clamshell-type variable-area exhaust nozzle. The engine was equipped with an electronic control that varied engine fuel flow and exhaust-nozzle area to maintain a schedule of turbine-outlet temperature and engine speed.

The original J40-WE-6 engine was modified before the investigation reported herein by replacing the compressor-outlet straightening-vane assembly with a two-element mixer-vane assembly, by using a slightly modified combustor basket, and by replacing the first-stage fixed turbine nozzles with a variable turbine-nozzle diaphragm. The original control was also modified to permit independent control of engine speed and exhaust-nozzle area.

Turbine

Both first- and second-stage turbine disks were solid steel and had an outer diameter of 21.90 inches. The first-stage rotor disk had 62 high-temperature-alloy blades fitted into its outer rim (fig. 3(a)) and the second stage contained 32 blades of the same material (fig. 3(b)). All turbine rotor blades were 5.50 inches in length; the turbine tip diameter was thus 32.90 inches and the hub-tip radius ratio was 0.666. The radial tip clearance for the turbine rotors was 5/32 inch.

The first-stage or variable turbine-nozzle diaphragm consisted of 56 high-temperature-alloy vanes which could be rotated between an inner and outer shroud (figs. 4(a) and 4(b)). All vanes were rotated simultaneously by an actuating mechanism similar to the one shown schematically in figure 5. The single actuating shaft extending through the engine outer skin was actuated by an externally mounted worm-gear drive. Changing the turbine-nozzle vane angle varied the nozzle throat area and also the angle that the fluid is turned in passing through the nozzles. Mid-vane cross sections of two adjacent turbine nozzle vanes are shown in the open and closed positions in figure 6. The solid-line section shows the vanes in the open position corresponding to a geometric throat area of 1.67 square feet and a turning angle at the throat of approximately 54.5°. The dashed-line section corresponds to the closed position with a throat area of 1.15 square feet and turning angle of about 62°. The original fixed turbine nozzles, for which the turbine rotors and second-stage nozzles were designed, corresponded closely to the variable turbine-nozzle setting that provided a throat area of 1.30 square feet and a turning angle of about 59°.

The second-stage or interstage stator consisted of 60 high-temperature-alloy vanes welded to an inner and outer shroud with a fixed nozzle-throat area of approximately 1.81 square feet. The annular passage through the turbine from first-stage nozzles to turbine outlet had approximately constant inner and outer diameters; the unblocked annular area was about 3.4 square feet.

Instrumentation

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Stations at which instrumentation was installed within the engine for measuring pressures and temperatures are shown in figure 2. The number of total and static pressure tubes, static pressure orifices, and thermocouples installed at each measuring station is shown in tabular form in this figure. Schematic sketches of the instrumentation at the cowl inlet (station 1), compressor outlet (station 4), turbine inlet (station 5), and turbine outlet (station 6) are shown in figure 7. Fuel flow was measured by calibrated rotameters and engine speed was measured by a stroboscopic tachometer.

Procedure

Data were obtained at altitudes of 15,000, 30,000, 40,000, and 44,000 feet at various flight Mach numbers from 0.14 to 0.62. Extensive performance data were obtained at an altitude of 30,000 feet and a flight Mach number of 0.62. At this flight condition, the variable turbine nozzles were set at five different positions and at each nozzle position the engine was operated at six different speeds from 3630 to 7260 rpm (rated speed). At each turbine-nozzle setting and engine speed, the exhaust nozzle was varied from the wide-open position to full closed, or until limiting turbine temperature was approached, to extend the range of turbine pressure ratio and corrected turbine speed. The ranges of turbine pressure ratio, corrected turbine speed, turbine nozzle area, and engine speed covered at this flight condition are shown in the following table:

Engine speed, rpm	3630 to 7260
Measured turbine-nozzle-throat area, sq ft	1.15 to 1.67
Turbine pressure ratio	1.57 to 3.00
Corrected turbine speed, rpm	2663 to 4407

The symbols and methods of calculation used to determine the turbine performance are given in the appendix.

RESULTS AND DISCUSSION

Inasmuch as the primary object is to show the effect of turbine nozzle area on turbine performance, curves are shown only for an altitude of 30,000 feet and a flight Mach number of 0.62 where the most extensive investigation was made. Data obtained at all of the flight conditions investigated are presented in numerical form in table I.

Corrected Turbine Gas Flow

The variation of corrected turbine gas flow with corrected turbine speed for all five turbine nozzle areas is shown in figure 8 for an altitude of 30,000 feet and a flight Mach number of 0.62. Although turbine pressure ratio is not a direct function of corrected turbine speed, lines of constant turbine pressure ratio have been superimposed to indicate approximately the general increase in turbine pressure ratio with increased corrected turbine speed at each turbine nozzle area. For each of the five nozzle areas, the corrected gas flow increased with corrected turbine speed to a maximum value and was unaffected by further increases in corrected turbine speed or turbine pressure ratio. Failure of the corrected gas flow to increase at high corrected turbine speeds (and high turbine pressure ratios) is attributed to choking of the flow at some station within the turbine. The turbine pressure ratio for choking varied from about 2.6 at a turbine nozzle area of 1.15 square feet to about 2.2 at an area of 1.67 square feet. However, these values of turbine pressure ratio at the transition point between choked and unchoked flow are very approximate because of the data inaccuracy in the low range of turbine pressure ratios.

The maximum corrected turbine gas flow (choked conditions) obtained at each nozzle area is shown in figure 9. This curve is also a measure of effective turbine-nozzle throat area inasmuch as corrected turbine gas flow is directly proportional to effective area when the nozzles are choked. Over the range of actual turbine nozzle areas from 1.15 to 1.67 square feet, the effective turbine nozzle area varied from 1.13 to 1.25 square feet for an effective area range of approximately 10 percent. It is apparent that the effective and measured areas are nearly equal at small area settings of the nozzles but the effective area is considerably smaller than the measured area at large area settings. This indicates a reduction in nozzle flow coefficient (defined as the ratio of effective area to measured area) from about 0.98 to 0.75 as the nozzles are opened. This large reduction in indicated flow coefficient may be caused by choking at some station within the turbine other than the inlet nozzles. However, inasmuch as interstage pressures and temperatures were not measured, the location of the choking station within the turbine could not be determined with certainty.

Turbine Efficiency

The turbine efficiencies obtained with all five turbine nozzle areas at an altitude of 30,000 feet and a flight Mach number of 0.62 are shown in figure 10 as a function of corrected turbine speed. The maximum turbine efficiency obtained was 0.87 with the smallest turbine nozzle area and a high corrected turbine speed. The minimum turbine efficiency was about 0.70 with the largest nozzle area and a low corrected turbine speed. In general, turbine efficiency increased with corrected turbine speed for all turbine nozzle areas and was lowered by increasing the turbine nozzle area (decreasing the nozzle turning angle) at a given corrected turbine speed. 2618 These general effects, however, are not clearly separated in figure 10 because the effects of turbine pressure ratio have not been accounted for.

In figures 11(a) and (b) to 15(a) and (b), operating lines of turbine pressure ratio and turbine efficiency are shown as functions of corrected turbine speed for each engine speed and turbine nozzle area. Although turbine efficiency is not a direct function of engine speed, lines of constant engine speed have been faired for the turbine efficiency data for the purpose of obtaining cross plots. The cross plots of turbine efficiency against corrected turbine speed for constant values of turbine pressure ratio obtained from parts (a) and (b) of figures 11 to 15 are shown in parts (c) of these figures. At a constant turbine pressure ratio, turbine efficiency increased with increased corrected turbine speed. This trend occurred at all values of constant turbine pressure ratio for which cross plots could be obtained at each turbine nozzle area. The maximum range of corrected turbine speed obtainable at a constant turbine pressure ratio was about 200 rpm and the average increase in turbine efficiency for this increase in corrected turbine speed was about 4 percent. However, the rate of increase in turbine efficiency with increased corrected turbine speed was greater at the lower values of constant turbine pressure ratio. At a given corrected turbine speed, turbine efficiency increased with reduced turbine pressure ratio, but the corrected turbine speed could be maintained constant only for a very small range of turbine pressure ratios.

The effect of changing turbine nozzle area and turning angle on turbine efficiency at a given corrected turbine speed and turbine pressure ratio is shown in figure 16. The symbols, which represent cross-plotted data points rather than actual data points, have been included to indicate the accuracy of the cross-plotted data as well as for distinguishing between turbine nozzle areas. In all cases where a comparison could be made at the same turbine pressure ratio and corrected turbine speed, the turbine efficiency was lowered by increasing the turbine nozzle area. Changing the turbine nozzle area from 1.30 to 1.67 square feet at constant values of corrected turbine speed and turbine pressure ratio

lowered the turbine efficiency by 3 or 4 percent. It is probable that the reduction in turbine efficiency over the complete range of turbine nozzle areas (decreasing the turning angle about $7\frac{1}{2}^{\circ}$) would not be more than about 5 or 6 percent in the region of high corrected turbine speeds and turbine pressure ratios.

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A comparison of turbine efficiencies obtained with the original fixed turbine nozzles and with the variable turbine nozzles at a corresponding area setting and at the same flight conditions and engine speed is shown in figure 17. The slightly lower turbine efficiency of about 1 percent (which is less than the data accuracy spread) obtained with the variable turbine nozzles indicates that the leakage losses with the variable nozzles were very small.

Mechanical Reliability

The variable-area turbine-nozzle diaphragm was installed in the engine during approximately 240 hours of engine operation and only minor mechanical difficulties were encountered during this period. Although the turbine nozzle area was not varied frequently during the part of the engine investigation reported herein, a great many changes in nozzle area were made during other parts of the investigation. The nozzles were at low physical loading conditions most of the time because most of the investigation was conducted at high altitudes, but inasmuch as a large part of the total operating time was at military speed and temperature, it is felt that these tests were a good indication of variable turbine nozzle life. Calibrations of turbine-nozzle-throat dimensions versus indicated nozzle setting showed good reproducibility of turbine nozzle areas.

CONCLUDING REMARKS

The variable-area turbine nozzles were found to be mechanically reliable and to have negligible leakage losses. It was possible to achieve a variation in corrected turbine gas flow or effective turbine nozzle area of about 10 percent by use of these variable turbine nozzles. At a given corrected turbine speed and turbine pressure ratio, changing the turbine nozzle area from 1.30 to 1.67 square feet lowered the turbine efficiency by 3 or 4 percent. The effect of increasing the turbine nozzle area from 1.15 to 1.67 square feet (decreasing the turning angle about $7\frac{1}{2}^{\circ}$) would probably lower the turbine efficiency about 5 or 6 percent.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio

APPENDIX - CALCULATIONS

Symbols

The following symbols are used in this report:

A	cross-sectional area, sq ft
g	acceleration due to gravity, 32.2 ft/sec^2
H	enthalpy of air or gas mixture, Btu/lb 2618
N	engine speed, rpm
P	total pressure, lb/sq ft absolute
p	static pressure, lb/sq ft absolute
R	gas constant, 53.4 ft-lb/lb-$^{\circ}$R
T	total temperature, $^{\circ}$R
T_i	indicated temperature, $^{\circ}$R
V	velocity, ft/sec
W_a	air flow, lb/sec
W_f	fuel flow, lb/hr
W_g	gas flow, lb/sec
α	thermocouple impact recovery factor, 0.85
γ	ratio of specific heats for gases
δ	pressure correction factor, $P/2116$ (total pressure divided by NACA standard sea-level pressure)
η	adiabatic efficiency
θ	temperature correction factor, $\gamma T/(1.4)(519)$, (product of γ and total temperature divided by product of γ and temperature for air at NACA standard sea-level conditions)
ρ	density, slugs/cu ft

Corrected parameters:

$N/\sqrt{\theta_5}$	corrected turbine speed, rpm
T_5/θ_2	corrected turbine-inlet temperature, ^{o}R
$\dfrac{W_g\sqrt{\theta_5}}{\delta_5(\gamma_5/1.4)}$	corrected turbine-inlet gas flow, lb/sec
$\Delta H_t/\theta_5$	corrected turbine enthalpy drop, Btu/lb

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Subscripts:

a	air
g	gas mixture
t	turbine
1	cowl inlet
2	compressor inlet
4	compressor outlet
5	turbine inlet
6	turbine outlet

Methods of Calculation

Total temperatures were calculated from thermocouple indicated temperatures with the equation

$$T = \frac{T_i\left(\frac{P}{p}\right)^{\frac{\gamma-1}{\gamma}}}{1 + \alpha\left[\left(\frac{P}{p}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]} \tag{1}$$

Air flow. - Air flow was determined from pressure and temperature measurements at the cowl inlet (station 1) by use of the equation

$$W_{a,1} = g\rho_1 A_1 V_1 = A_1\sqrt{\frac{2g}{R}}\left(\frac{P_1}{\sqrt{T_1}}\right)\sqrt{\left(\frac{\gamma_1}{\gamma_1-1}\right)\left(\frac{P_1}{p_1}\right)^{\frac{\gamma_1-1}{\gamma_1}}\left[\left(\frac{P_1}{p_1}\right)^{\frac{\gamma_1-1}{\gamma_1}} - 1\right]} \qquad (2)$$

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Gas flow. - Gas flow was calculated from fuel-flow measurements and cowl-inlet air flow as follows:

$$W_g = W_{a,1} + W_f/3600 \qquad (3)$$

Turbine-inlet temperature. - Turbine-inlet temperature was determined from the enthalpy and fuel-air ratio at the turbine inlet by use of temperature-enthalpy tables. Turbine-inlet enthalpy was calculated from the following equation which assumes that the turbine enthalpy drop equals the compressor enthalpy rise:

$$H_{g,5} = H_{g,6} + \frac{W_{a,1}}{W_g}(H_{a,4} - H_{a,2}) \qquad (4)$$

Turbine efficiency. - The turbine adiabatic efficiency was determined from the following equation:

$$\eta_t = \frac{1 - \frac{T_6}{T_5}}{1 - \left(\frac{P_6}{P_5}\right)^{\frac{\gamma_t-1}{\gamma_t}}} \qquad (5)$$

where γ_t is the average value of γ between stations 5 and 6.

REFERENCES

1. Silvern, David H., and Slivka, William R.: Analytical Investigation of Turbines with Adjustable Stator Blades and Effect of These Turbines on Jet-Engine Performance. NACA RM E50E05, 1950.

TABLE I. - VARIABLE-AREA TURBINE PERFORMANCE

Run	Altitude (ft)	M_0	P_0 $\left(\frac{lb}{sq\ ft}\right)$	Turbine nozzle area (sq ft)	N (rpm)	W_f $\left(\frac{lb}{hr}\right)$	P_2 $\left(\frac{lb}{sq\ ft}\right)$	T_2 (°R)	T_4 (°R)	P_5 $\left(\frac{lb}{sq\ ft}\right)$	T_5 (°R)	P_6 $\left(\frac{lb}{sq\ ft}\right)$	T_6 (°R)	$W_{a,1}$ $\left(\frac{lb}{sec}\right)$	$W_{g,5}$ $\left(\frac{lb}{sec}\right)$	η_t	P_5/P_6	$\frac{N}{\sqrt{\theta_5}}$ (rpm)	$\frac{\Delta H_t}{\theta_5}$ $\left(\frac{Btu}{lb}\right)$	$\frac{T_5}{\theta_2}$ (°R)	$\frac{W_{g,5}\sqrt{\theta_5}}{\delta_5}\left(\frac{\gamma_5}{1.4}\right)$ $\left(\frac{lb}{sec}\right)$	$\frac{W_f}{W_{a,1}(3600)}$	$\frac{T_5}{T_6}$
1	15,000	0.424	1185	1.15	7260	3140	1340	499	855	----	----	----	1191	-----	-----	------	-----	----	----	----	-----	------	----
2		.464	1189	1.15	7260	3525	1379	495	858	6421	1563	2210	1239	95.40	96.38	0.8637	2.905	4281	30.2	1640	56.36	0.0103	1.262
3		.464	1189	1.15	7260	3955	1379	494	866	6625	1660	2370	1325	95.46	96.56	.8773	2.795	4163	29.7	1745	56.53	.0115	1.253
4		.460	1196	1.15	7260	4340	1382	494	871	6794	1720	2479	1382	95.72	96.93	.8733	2.740	4095	29.2	1808	56.42	.0126	1.245
5		.467	1188	1.15	7260	4795	1379	494	880	6964	1850	2659	1503	95.46	96.79	.8849	2.619	3956	27.9	1944	57.15	.0140	1.231
6		.459	1199	1.15	6897	2855	1385	495	824	5979	1410	2016	1116	93.23	94.02	.8407	2.965	4268	30.4	1479	55.86	.0085	1.263
7		.455	1191	1.15	6897	3515	1372	491	837	6240	1560	2254	1251	92.67	93.65	.8613	2.768	4071	28.9	1649	56.34	.0105	1.247
8		.457	1200	1.15	6897	3765	1384	490	839	6384	1600	2376	1294	93.54	94.59	.8540	2.686	4022	28.2	1694	56.39	.0112	1.236
9		.453	1195	1.15	6897	4195	1375	490	849	6531	1704	2547	1386	92.98	94.15	.8801	2.564	3905	27.6	1805	56.76	.0125	1.229
10		.460	1198	1.15	6897	4610	1385	496	862	6710	1810	2669	1486	93.04	94.32	.8731	2.514	3800	26.7	1895	57.13	.0138	1.218
11		.464	1188	1.15	6353	2235	1377	492	781	5218	1300	1822	1036	84.84	85.46	.8289	2.963	4080	28.5	1372	55.75	.0073	1.255
12		.456	1191	1.15	6353	2590	1374	491	789	5357	1394	1968	1128	84.11	84.83	.8259	2.722	3951	27.5	1473	55.95	.0086	1.236
13		.456	1192	1.15	6353	3000	1375	491	801	5462	1485	2070	1213	83.50	84.33	.8252	2.638	3836	27.0	1570	56.45	.0100	1.224
14		.467	1186	1.15	6353	3250	1377	490	802	5621	1555	2235	1280	82.72	83.62	.6383	2.514	3757	25.9	1647	55.75	.0109	1.215
15		.457	1197	1.15	6353	3615	1381	491	809	5739	1650	2359	1369	81.88	82.88	.8430	2.432	3651	25.1	1744	55.86	.0123	1.205
16		.469	1183	1.15	5808	1800	1375	488	676	4364	1150	1669	966	73.73	74.23	.6996	2.615	3951	21.6	1225	54.25	.0068	1.190
17		.471	1186	1.15	5808	2115	1381	487	736	4482	1310	1742	1082	73.40	73.99	.7896	2.573	3718	25.0	1395	56.42	.0080	1.211
18		.472	1176	1.15	5808	2455	1370	486	743	4546	1420	1891	1191	70.28	70.96	.7895	2.404	3583	23.6	1515	55.75	.0097	1.192
19		.460	1186	1.15	5808	2795	1371	480	748	4631	1530	2029	1290	65.99	66.77	.8215	2.282	3459	23.1	1655	53.55	.0118	1.186
20		.455	1188	1.15	5808	3015	1369	488	763	4585	1630	2142	1386	68.71	69.55	.8540	2.141	3359	22.1	1736	58.26	.0122	1.176
21		.475	1176	1.15	4719	1095	1372	489	650	2869	1050	1314	898	52.10	52.40	.7534	2.183	3352	19.7	1114	55.51	.0058	1.169
22		.485	1182	1.15	4719	1229	1388	486	651	2982	1095	1420	938	52.17	52.51	.7853	2.100	3286	19.4	1168	54.78	.0065	1.167
23		.462	1185	1.15	4719	1365	1371	487	657	3005	1165	1500	1005	50.80	51.16	.8053	2.003	3193	18.7	1241	54.72	.0075	1.159
24		.472	1182	1.15	4719	1511	1377	487	663	3100	1230	1602	1063	49.70	50.12	.8424	1.935	3111	18.7	1310	53.47	.0084	1.157
25		.474	1186	1.15	4719	1639	1383	488	668	3146	1290	1628	1124	49.19	49.65	.8069	1.932	3045	18.3	1374	53.51	.0093	1.148
26		.467	1180	1.15	3630	785	1370	485	580	2032	940	1217	850	36.81	37.03	.7258	1.670	2717	12.3	1005	52.31	.0059	1.106
27		.472	1177	1.15	3630	879	1371	485	584	2069	990	1283	902	36.17	36.41	.7234	1.613	2652	12.3	1058	51.91	.0068	1.098
28		.482	1192	1.15	3630	965	1397	485	588	2163	1055	1384	961	36.20	36.47	.7795	1.563	2574	12.1	1123	51.42	.0074	1.098
29		.460	1193	1.30	7260	3370	1379	483	812	5924	1480	2124	1190	96.96	97.90	.8394	2.789	4392	28.9	1591	60.30	.0097	1.244
30		.463	1183	1.30	7260	3785	1369	493	836	----	1593	----	1289	95.29	96.34	------	-----	4243	28.0	1677	-----	.0110	1.236
31		.459	1192	1.30	7260	4495	1377	489	844	6359	1743	2558	1430	96.18	97.43	.8782	2.486	4070	26.7	1849	61.02	.0130	1.219
32		.464	1187	1.30	6897	3005	1376	495	803	5553	1430	2027	1153	92.54	93.37	.8364	2.739	4239	28.0	1500	60.21	.0090	1.240
33		.463	1187	1.30	6897	3495	1374	495	815	5767	1540	2238	1258	92.42	93.39	.8477	2.576	4096	27.2	1615	60.39	.0105	1.224
34		.462	1190	1.30	6897	3855	1377	494	823	5935	1627	2373	1332	92.73	93.80	.8716	2.501	3991	26.5	1710	60.64	.0115	1.221
35		.463	1184	1.30	6897	4450	1371	496	831	6130	1748	2562	1446	92.11	93.35	.8803	2.392	3860	25.4	1830	60.74	.0134	1.209
36		.464	1186	1.30	6353	2400	1375	493	764	4923	1327	1855	1083	86.00	86.67	.8080	2.653	4041	25.9	1397	60.59	.0078	1.225
37		.464	1185	1.30	6353	2890	1374	492	775	5113	1433	2051	1180	85.39	86.19	.8318	2.493	3900	25.6	1512	60.44	.0094	1.214
38		.462	1188	1.30	6353	3390	1374	491	785	5316	1563	2256	1301	84.45	85.39	.8490	2.356	3746	24.7	1652	60.37	.0112	1.201
39		.463	1188	1.30	6353	3885	1375	490	794	5501	1680	[illegible]	1412	83.61	84.69	.8548	2.268	3622	23.7	1779	60.14	.0129	1.190
40		.460	1188	1.30	6353	4390	1374	489	799	5616	1800	2573	1531	82.61	83.83	.8494	2.182	3510	22.6	1910	60.50	.0146	1.176
41		.464	1186	1.30	5808	1865	1374	491	724	4144	1230	1665	1007	75.77	76.29	.8363	2.488	3829	24.7	1300	60.85	.0068	1.221
42		.464	1187	1.30	5808	2230	1376	487	727	4310	1323	1823	1103	75.17	75.79	.8160	2.364	3702	23.5	1409	60.41	.0082	1.199
43		.463	1185	1.30	5808	2500	1372	488	733	4361	1410	1933	1194	73.53	74.22	.8004	2.256	3594	22.6	1502	60.48	.0094	1.181
44		.467	1184	1.30	5808	2890	1374	488	743	4477	1540	2073	1310	72.34	73.14	.8332	2.159	3449	21.9	1640	60.91	.0111	1.176
45		.459	1188	1.30	5808	3295	1372	487	753	4570	1673	2195	1437	70.28	71.20	.8384	2.082	3319	20.9	1782	60.73	.0130	1.164
46		.464	1187	1.30	4719	1175	1375	486	644	2798	1083	1410	933	52.38	52.71	.8123	1.984	3302	18.6	1156	58.23	.0062	1.161
47		.467	1185	1.30	4719	1295	1375	483	643	----	1147	----	988	52.53	52.89	------	-----	3215	18.1	1233	-----	.0068	1.161
48		.471	1184	1.30	4719	1530	1378	481	646	2941	1243	1576	1080	52.06	52.49	.8563	1.866	3096	17.6	1342	59.33	.0082	1.151
49		.464	1186	1.30	4719	1655	1374	482	653	3004	1293	1630	1137	51.21	51.67	.8112	1.842	3041	17.4	1393	58.39	.0090	1.137
50		.466	1184	1.30	4719	1740	1374	480	653	----	1330	----	1168	51.32	51.80	------	-----	3000	17.4	1439	-----	.0094	1.139
51		.470	1183	1.30	3630	814	1375	484	573	1967	955	1282	868	37.71	37.94	.8178	1.534	2699	12.2	1023	55.81	.0060	1.100
52		.467	1185	1.30	3630	1022	1375	483	582	2086	1108	1192	1009	36.36	36.64	.6386	1.750	2514	11.5	1191	54.97	.0078	1.098
53		.463	1190	1.67	7260	3840	1378	485	813	5797	1573	----	1279	96.36	97.43	------	-----	4268	27.3	1682	63.35	.0111	1.230
54		.460	1180	1.67	7260	4040	1364	497	827	5820	1643	----	1348	94.20	95.32	------	-----	4182	26.5	1715	63.20	.0119	1.219
55		.463	1186	1.67	7260	4310	1373	491	824	5956	1680	1920	1384	95.40	96.60	.7082	3.102	4139	26.0	1776	63.37	.0125	1.214
56		.457	1183	1.67	7260	4720	1365	493	837	6090	1780	2180	1480	94.64	95.95	.7459	2.794	4031	25.3	1874	63.44	.0139	1.203

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TABLE I. - VARIABLE-AREA TURBINE PERFORMANCE - Continued

Run	Altitude (ft)	M_0	p_0 (lb/sq ft)	Turbine nozzle area (sq ft)	N (rpm)	W_f (lb/hr)	P_2 (lb/sq ft)	T_2 (°R)	T_4 (°R)	P_5 (lb/sq ft)	T_5 (°R)	P_6 (lb/sq ft)	T_6 (°R)	$W_{a,1}$ (lb/sec)	$W_{g,5}$ (lb/sec)	η_t	P_5/P_6	$\frac{N}{\sqrt{\theta_5}}$ (rpm)	$\frac{\Delta H_t}{\theta_5}$ (Btu/lb)	$\frac{T_5}{\theta_2}$ (°R)	$\frac{W_{g,5}\sqrt{\theta_5}}{\delta_5}\left(\frac{\gamma_5}{1.4}\right)$ (lb/sec)	$\frac{W_f}{W_{a,1}(3600)}$	$\frac{T_5}{T_6}$
57	15,000	0.453	1188	1.67	7260	5030	1368	487	830	6210	1830	2307	1525	95.40	96.80	0.7661	2.692	3978	24.9	1949	63.72	0.0146	1.200
58		.455	1183	1.67	6897	3370	1362	504	807	5374	1507	----	1235	90.85	91.79	------	-----	4135	26.3	1552	62.92	.0103	1.220
59		.460	1186	1.67	6897	3765	1371	497	805	5571	1580	1951	1302	92.05	93.10	.7473	2.855	4048	25.8	1650	63.14	.0114	1.214
60		.464	1186	1.67	6897	4065	1375	500	813	5677	1650	2123	1370	91.99	93.12	.7696	2.674	3964	25.1	1713	63.45	.0123	1.204
61		.467	1186	1.67	6897	4480	1377	496	817	6876	1730	2205	1448	92.48	93.72	.7487	2.665	3881	24.4	1811	63.24	.0135	1.195
62		.460	1181	1.67	6897	4890	1365	499	827	5993	1825	2361	1536	91.45	92.81	.7689	2.538	3785	23.8	1898	63.21	.0148	1.188
63		.464	1186	1.67	6353	2695	1374	499	762	4786	1370	1853	1136	85.43	86.18	.7729	2.583	3983	24.8	1425	63.03	.0088	1.206
64		.464	1191	1.67	6353	3160	1381	497	769	5016	1473	2024	1230	85.33	86.21	.7868	2.478	3850	24.3	1538	62.51	.0103	1.198
65		.457	1183	1.67	6353	3645	1365	496	777	5134	1600	2190	1349	84.49	85.50	.8054	2.344	3707	22.8	1675	63.34	.0120	1.186
66		.459	1186	1.67	8353	4075	1370	496	789	5313	1703	2377	1442	83.50	84.63	.8377	2.235	3601	22.8	1783	62.69	.0136	1.181
67		.462	1187	1.67	6353	4450	1374	498	792	5428	1793	2486	1537	82.84	84.08	.8123	2.483	3516	21.5	1868	62.68	.0149	1.167
68		.462	1181	1.67	5808	2090	1366	473	674	4092	1215	1690	1023	77.08	77.66	.7488	2.421	3854	21.6	1332	62.36	.0075	1.188
69		.462	1182	1.67	5808	2500	1368	487	722	4204	1377	1806	1168	75.38	76.07	.7840	2.328	3632	21.9	1467	63.53	.0092	1.179
70		.459	1190	1.67	5808	2965	1375	486	733	4360	1520	2002	1301	74.55	75.37	.7944	2.178	3470	21.1	1622	64.02	.0110	1.168
71		.460	1188	1.67	5808	3230	1373	483	734	4430	1600	2138	1375	73.30	74.20	.8320	2.072	3389	20.4	1720	63.66	.0122	1.164
72		-----	1184	1.67	5808	3595	----	484	676	4504	----	2298	1485	-----	-----	------	1.960	----	----	----	------	------	-----
73		.471	1181	1.67	4719	1250	1375	510	660	2624	1143	1329	996	49.15	49.50	.7664	1.974	3221	17.2	1164	59.97	.0071	1.148
74		.467	1195	1.67	4719	1445	1387	501	657	2761	1197	1428	1045	50.73	51.13	.7844	1.933	3152	17.0	1240	60.36	.0079	1.145
75		.464	1188	1.67	4719	1595	1377	499	658	2792	1255	1528	1106	49.10	49.54	.8037	1.827	3084	16.6	1305	59.35	.0090	1.135
76		.460	1188	1.67	4719	1705	1374	502	664	2841	1323	1624	1173	48.84	49.31	.8296	1.749	3010	16.3	1368	59.68	.0097	1.128
77		.472	1184	1.67	4719	1910	1379	493	662	2903	1400	1733	1246	51.51	52.04	.8772	1.675	2929	15.8	1474	63.52	.0103	1.124
78		.467	1186	1.67	3630	892	1377	486	574	1967	983	1222	900	37.69	37.94	.6918	1.610	2661	11.3	1049	56.71	.0066	1.092
79		.460	1183	1.67	3630	972	1368	483	572	1997	1023	1274	944	37.53	37.80	.6696	1.568	2612	10.4	1100	56.76	.0072	1.084
80		.459	1186	1.67	3630	1060	1370	488	579	2027	1103	1342	1017	36.72	37.01	.7415	1.510	2521	10.6	1175	56.98	.0060	1.085
81		.469	1182	1.67	3630	1123	1373	485	579	2076	1130	1388	1043	36.24	36.55	.7527	1.496	2493	10.4	1208	55.67	.0086	1.083
82	30,000	0.632	605	1.15	7260	1979	791	459	809	3729	1480	1245	1168	57.07	57.62	0.8541	2.995	4392	30.8	1672	56.39	0.0096	1.267
83		.619	616	1.15	7260	2255	797	473	837	3892	1615	1356	1283	56.49	57.12	.8693	2.870	4216	30.0	1770	56.13	.0111	1.259
84		.607	621	1.15	7260	2480	796	471	844	3997	1693	1440	1360	56.50	57.19	.8635	2.776	4125	29.1	1867	56.08	.0122	1.245
85		.621	614	1.15	7260	2810	797	465	845	4135	1803	1541	1467	56.66	57.44	.8562	2.683	4007	27.7	2010	56.33	.0138	1.229
86		-----	620	1.15	7260	3020	797	463	844	4202	----	1599	1518	-----	-----	------	2.628	----	----	----	-----	------	-----
87		.621	626	1.15	6897	1710	812	475	801	3593	1393	1198	1099	57.00	57.48	.8410	2.999	4289	30.2	1521	56.49	.0083	1.269
88		.621	619	1.15	6897	1905	803	475	810	3659	1477	1260	1177	56.33	56.86	.8379	2.904	4175	29.7	1613	56.64	.0094	1.255
89		.611	622	1.15	6897	2115	800	471	816	3748	1573	1342	1265	56.25	56.84	.8454	2.793	4055	28.7	1735	57.11	.0104	1.243
90		.610	620	1.15	6897	2490	797	469	826	3888	1710	1467	1393	55.90	56.59	.8497	2.650	3901	27.5	1893	57.37	.0124	1.228
91		.618	615	1.15	6897	2935	795	466	832	4045	1857	1601	1541	55.57	56.39	.8319	2.527	3754	25.8	2067	57.42	.0147	1.205
92		.628	615	1.15	6353	1323	802	475	762	3111	1270	1047	1000	51.17	51.54	.8413	2.971	4125	29.6	1387	55.70	.0072	1.270
93		.619	619	1.15	6353	1445	801	479	770	3149	1337	1096	1070	50.87	51.27	.8191	2.873	4029	28.1	1449	56.26	.0079	1.250
94		.624	618	1.15	6353	1567	804	477	772	3226	1370	1148	1107	51.07	51.51	.8067	2.810	3983	27.5	1491	55.85	.0085	1.238
95		.616	618	1.15	6353	1688	798	479	779	3258	1430	1197	1161	50.49	50.96	.8182	2.722	3902	27.2	1550	56.02	.0093	1.232
96		.624	617	1.15	6353	1786	802	479	781	3302	1455	1232	1194	50.69	51.19	.7938	2.680	3874	26.8	1577	56.08	.0098	1.219
97		.623	615	1.15	5808	997	799	477	720	2600	1150	921	915	46.04	46.32	.8319	2.823	3951	27.3	1251	56.78	.0060	1.257
98		.611	624	1.15	5808	1169	802	476	724	2650	1240	993	1006	46.14	46.46	.8162	2.669	3816	25.9	1352	58.20	.0070	1.233
99		.619	622	1.15	5808	1333	805	474	730	2723	1315	1062	1082	46.16	46.53	.8033	2.564	3711	25.3	1439	58.54	.0080	1.215
100		.616	621	1.15	5808	1498	802	475	737	2754	1400	1116	1164	45.72	46.14	.8017	2.468	3605	24.3	1529	59.34	.0091	1.203
101		.622	616	1.15	5808	1614	800	474	745	2779	1477	1155	1233	45.47	45.92	.8130	2.406	3518	24.2	1616	60.23	.0099	1.198
102		.627	621	1.15	4719	641	809	476	638	1701	963	750	808	32.34	32.52	.7947	2.268	3493	21.4	1050	55.56	.0055	1.192
103		.621	621	1.15	4719	709	805	471	636	1738	1015	786	853	31.16	31.35	.8130	2.211	3407	20.8	1120	53.86	.0063	1.190
104		.624	618	1.15	4719	773	804	473	643	1764	1070	820	905	31.03	31.24	.8180	2.151	3323	20.3	1173	54.38	.0069	1.182
105		.613	622	1.15	4719	867	801	471	647	1805	1157	869	987	30.60	30.84	.8216	2.077	3204	19.8	1276	54.70	.0079	1.172
106		.622	619	1.15	4719	964	804	471	654	1864	1230	911	1055	29.90	30.17	.8197	2.046	3113	19.6	1357	53.53	.0090	1.166
107		.614	618	1.15	3630	526	797	470	562	1147	800	668	711	23.75	23.90	.7939	1.717	2937	14.4	884	55.00	.0062	1.125
108		.619	620	1.15	3630	562	802	468	557	1154	823	694	741	23.95	24.11	.7528	1.663	2899	12.8	913	55.94	.0065	1.111
109		.625	620	1.15	3630	579	807	469	565	----	----	717	774	-----	-----	-----	-----	----	----	----	-----	------	-----
110		.626	617	1.15	3630	605	803	466	564	1206	907	729	820	23.19	23.36	.7371	1.654	2767	12.8	1006	54.55	.0072	1.106
111		.616	612	1.20	7260	2060	791	460	793	3613	1470	1259	1178	57.19	57.76	.8289	2.870	4405	29.1	1658	58.15	.0100	1.248
112		.621	611	1.20	7260	2250	792	460	805	3737	1560	1319	1256	57.12	57.75	.8294	2.833	4286	28.6	1760	58.00	.0109	1.242

TABLE I. - VARIABLE-AREA TURBINE PERFORMANCE - Continued

Run	Altitude (ft)	M_0	p_0 $\left(\frac{lb}{sq\ ft}\right)$	Turbine nozzle area (sq ft)	N (rpm)	W_f $\left(\frac{lb}{hr}\right)$	P_2 $\left(\frac{lb}{sq\ ft}\right)$	T_2 (^{o}R)	T_4 (^{o}R)	P_5 $\left(\frac{lb}{sq\ ft}\right)$	T_5 (^{o}R)	P_6 $\left(\frac{lb}{sq\ ft}\right)$	T_6 (^{o}R)	$W_{a,1}$ $\left(\frac{lb}{sec}\right)$	$W_{g,5}$ $\left(\frac{lb}{sec}\right)$	η_t	P_5/P_6	$\frac{N}{\sqrt{\theta_5}}$ (rpm)	$\frac{\Delta H_t}{\theta_5}$ $\left(\frac{Btu}{lb}\right)$	$\frac{T_5}{\theta_2}$ (^{o}R)	$\frac{W_{g,5}\sqrt{\theta_5}}{\delta_5}\left(\frac{\gamma_5}{1.4}\right)$ $\left(\frac{lb}{sec}\right)$	$\frac{W_f}{W_{a,1}(3600)}$	$\frac{T_5}{T_6}$
113	30,000	0.618	614	1.20	7260	2390	794	462	809	3806	1610	1382	1301	57.02	57.68	0.8006	2.754	4221	28.4	1810	57.86	0.0116	1.238
114		.614	614	1.20	7260	2590	792	459	812	3888	1673	1445	1365	57.02	57.74	.8308	2.691	4149	27.4	1890	57.92	.0126	1.226
115		.614	614	1.20	7260	2765	792	458	815	3960	1733	1509	1422	56.99	57.76	.8341	2.624	4081	26.9	1962	57.93	.0135	1.219
116		.616	612	1.20	6897	1770	790	463	774	3434	1367	----	1086	56.23	56.72	------	-----	4330	29.6	1532	57.73	.0087	1.259
117		.626	612	1.20	6897	2020	797	462	785	3575	1480	1292	1196	56.66	57.22	.8264	2.767	4173	28.2	1664	58.39	.0099	1.237
118		.621	617	1.20	6897	2305	801	462	795	3722	1590	1404	1294	56.86	57.50	.8433	2.651	4034	27.4	1787	58.58	.0113	1.229
119		.611	614	1.20	6897	2595	789	460	804	3796	1713	1492	1412	55.98	56.70	.8391	2.544	3899	26.2	1932	58.92	.0129	1.213
120		.616	615	1.20	6897	2965	794	479	839	3880	1860	1595	1544	54.71	55.53	.8616	2.433	3753	25.7	2016	58.97	.0151	1.205
121		.634	605	1.20	6897	3030	792	460	813	3974	1847	1621	1540	55.93	56.77	.8360	2.452	3763	25.0	2083	58.67	.0150	1.199
122		.624	612	1.20	6353	1375	795	462	736	3048	1177	1074	912	52.79	53.17	.9154	2.838	4278	30.3	1323	56.33	.0072	1.291
123		.614	608	1.20	6353	1515	784	460	740	3099	1277	1121	1019	51.99	52.41	.8487	2.764	4117	28.1	1440	57.01	.0081	1.253
124		.619	612	1.20	6353	1700	792	460	746	3208	1355	1204	1099	52.43	52.90	.8296	2.664	4006	27.0	1528	57.36	.0090	1.233
125		.634	607	1.20	6353	1910	796	461	753	3307	1440	1274	1183	52.37	52.90	.8106	2.596	3893	26.3	1621	57.54	.0101	1.217
126		.628	615	1.20	6353	2095	802	461	758	3401	1530	1366	1267	52.70	53.28	.8217	2.490	3784	25.2	1723	58.21	.0110	1.208
127		.624	612	1.20	5808	1030	796	460	686	2542	1080	932	860	46.77	47.06	.8477	2.727	4070	27.0	1218	57.13	.0061	1.256
128		-----	---	1.20	5808	1112	---	457	659	2589	----	966	901	-----	-----	------	2.680	----	----	----	-----	------	-----
129		.621	606	1.20	5808	1245	785	457	695	2634	1200	1014	971	45.87	46.22	.8424	2.597	3877	25.8	1363	57.27	.0075	1.236
130		.614	610	1.20	5808	1334	787	460	701	2663	1243	1054	1019	45.77	46.14	.8210	2.527	3811	24.9	1402	57.57	.0081	1.220
131		.633	612	1.20	5808	1436	801	460	705	2766	1280	1102	1061	46.38	46.78	.7885	2.510	3762	24.2	1444	57.14	.0086	1.206
132		.624	605	1.20	4719	700	786	459	614	1695	940	746	796	32.40	32.59	.7536	2.272	3535	20.1	1062	55.17	.0060	1.181
133		.624	609	1.20	4719	710	792	458	613	1684	950	760	809	32.87	33.07	.7510	2.216	3516	19.9	1075	56.64	.0060	1.174
134		.629	609	1.20	4719	735	795	456	612	1693	973	782	830	32.85	33.05	.7656	2.165	3475	19.4	1107	57.05	.0062	1.172
135		.630	607	1.20	4719	800	793	459	619	1731	1043	818	893	33.27	33.49	.7765	2.115	3364	19.2	1179	58.60	.0067	1.168
136		.630	609	1.20	4719	910	795	458	622	1786	1123	871	970	33.00	33.25	.7727	2.050	3248	17.9	1271	58.66	.0077	1.158
137		.624	605	1.20	4719	985	786	457	630	----	----	909	1017	-----	-----	------	-----	----	---	----	-----	------	-----
138		.623	607	1.20	3630	560	789	460	546	1133	790	668	708	23.75	23.91	.7560	1.696	2956	13.8	891	55.35	.0066	1.116
139		.624	607	1.20	3630	560	789	459	546	1128	800	----	713	23.79	23.95	------	-----	2939	13.7	904	56.05	.0065	1.122
140		.624	610	1.20	3630	580	793	459	546	1149	810	685	726	23.51	23.67	.7704	1.677	2920	13.5	915	54.73	.0069	1.116
141		.626	608	1.20	3630	630	792	460	549	1174	855	710	773	23.05	23.23	.7366	1.653	2847	12.8	964	54.07	.0076	1.106
142		.626	610	1.20	3630	660	794	460	552	1204	905	736	822	22.72	22.90	.7203	1.636	2771	12.1	1021	53.54	.0081	1.101
143		.616	611	1.30	7260	2020	789	453	778	3497	1473	1258	1185	57.49	58.05	.8380	2.780	4400	28.7	1690	60.40	.0098	1.243
144		.622	607	1.30	7260	2350	788	454	794	3638	1593	1356	1293	57.27	57.92	.8436	2.683	4243	27.7	1821	60.41	.0114	1.232
145		.625	605	1.30	7260	2645	787	455	806	3759	1703	1449	1393	56.97	57.70	.8521	2.594	4113	27.0	1943	60.40	.0129	1.223
146		.623	607	1.30	7260	2975	789	456	817	3886	1810	1557	1498	56.90	57.73	.8476	2.496	4000	26.1	2060	60.39	.0145	1.208
147		.590	622	1.30	7260	3245	787	457	821	3963	1890	1627	1582	56.68	57.58	.8308	2.436	3922	25.1	2147	60.44	.0159	1.195
148		.613	611	1.30	6897	1805	787	459	765	3338	1403	1241	1127	56.23	56.73	.8616	2.690	4279	28.5	1585	60.23	.0089	1.245
149		.619	615	1.30	6897	2050	796	460	775	3480	1493	1294	1210	56.83	57.40	.8378	2.689	4155	27.6	1684	60.42	.0100	1.234
150		.613	621	1.30	6897	2390	800	460	785	3631	1610	1420	1321	57.03	57.69	.8439	2.557	4010	26.7	1816	60.63	.0116	1.219
151		.618	620	1.30	6897	2775	802	461	796	3785	1743	1547	1447	56.94	57.71	.8477	2.447	3866	25.5	1963	60.71	.0135	1.205
152		.618	620	1.30	6897	3125	802	459	804	3933	1853	1657	1559	56.81	57.68	.8253	2.374	3759	24.1	2094	60.34	.0153	1.189
153		.621	620	1.30	6353	1480	804	463	731	3033	1285	1110	1034	53.48	53.89	.8318	2.732	4104	27.1	1440	60.14	.0077	1.243
154		.622	617	1.30	6353	1685	801	462	738	3106	1367	1191	1115	53.05	53.52	.8273	2.608	3988	26.4	1537	60.23	.0088	1.226
155		.626	617	1.30	6353	1905	803	463	746	3222	1463	1284	1207	53.01	53.54	.8247	2.509	3864	25.5	1640	60.24	.0100	1.212
156		.628	605	1.30	6353	2090	789	463	753	3241	1543	1338	1291	51.89	52.47	.8044	2.422	3768	24.3	1730	60.42	.0112	1.195
157		.627	615	1.30	6353	2390	801	463	759	3387	1643	1450	1381	52.53	53.19	.8251	2.336	3662	23.6	1842	60.58	.0126	1.190
158		.607	613	1.30	5808	1083	786	460	685	2462	1130	935	907	46.15	46.45	.8534	2.633	3986	26.4	1275	59.59	.0065	1.246
159		.621	607	1.30	5808	1480	787	462	705	2639	1347	1112	1126	45.71	46.12	.8068	2.373	3671	23.6	1514	60.63	.0090	1.196
160		.614	613	1.30	5808	1690	791	462	712	2717	1443	1190	1228	45.62	46.09	.7732	2.283	3554	22.1	1622	61.09	.0103	1.175
161		.616	608	1.30	5808	1875	786	462	720	2744	1567	1247	1335	45.18	45.70	.8115	2.200	3420	21.5	1761	62.65	.0115	1.174
162		.619	619	1.30	5808	2080	801	462	724	2846	1643	1315	1416	45.75	46.33	.7799	2.164	3348	20.6	1847	62.81	.0126	1.160
163		.634	615	1.30	4719	700	806	461	613	1657	----	764	----	33.97	34.16	------	2.169	----	----	----	-----	.0057	-----
164		.616	614	1.30	4719	791	793	461	615	1687	1043	810	890	32.99	33.21	.8078	2.083	3364	19.3	1174	59.63	.0067	1.172
165		.640	610	1.30	4719	850	803	460	619	1728	1070	846	921	33.06	33.30	.7883	2.043	3323	18.8	1207	59.18	.0071	1.162
166		.623	612	1.30	4719	951	795	463	631	1764	----	897	----	32.21	32.47	------	1.967	----	----	----	-----	.0082	-----
167		.616	612	1.30	4719	1009	790	465	634	1771	1223	920	1072	31.56	31.84	.7719	1.925	3121	17.1	1364	59.30	.0089	1.141
168		.636	611	1.30	3630	553	801	461	544	1102	795	672	717	24.92	25.07	.7599	1.640	2946	12.5	895	59.87	.0062	1.109

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TABLE I. - VARIABLE-AREA TURBINE PERFORMANCE - Continued

Run	Altitude (ft)	M_0	p_0 $\left(\frac{lb}{sq\ ft}\right)$	Turbine nozzle area (sq ft)	N (rpm)	W_f $\left(\frac{lb}{hr}\right)$	P_2 $\left(\frac{lb}{sq\ ft}\right)$	T_2 (°R)	T_4 (°R)	P_5 $\left(\frac{lb}{sq\ ft}\right)$	T_5 (°R)	P_6 $\left(\frac{lb}{sq\ ft}\right)$	T_6 (°R)	$W_{a,1}$ $\left(\frac{lb}{sec}\right)$	$W_{g,5}$ $\left(\frac{lb}{sec}\right)$	η_t	P_5/P_6	$\frac{N}{\sqrt{\theta_5}}$ (rpm)	$\frac{\Delta H_t}{\theta_5}$ $\left(\frac{Btu}{lb}\right)$	$\frac{T_5}{\theta_2}$ (°R)	$\frac{W_{g,5}\sqrt{\theta_5}}{\delta_5}\left(\frac{\gamma_5}{1.4}\right)$ $\left(\frac{lb}{sec}\right)$	$\frac{W_f}{W_{a,1}(3600)}$	$\frac{T_5}{T_6}$
169	30,000	0.621	610	1.30	3630	635	791	460	546	1146	863	705	778	23.44	23.62	0.7811	1.626	2834	12.8	974	56.60	0.0075	1.109
170		.636	610	1.30	3630	698	801	460	550	1186	920	743	835	23.33	23.52	.7636	1.596	2748	12.0	1038	56.31	.0083	1.102
171		.599	623	1.37	7260	2130	794	468	798	3488	1527	1277	1234	56.95	57.54	.8398	2.731	4327	28.0	1693	61.22	.0104	1.237
172		.619	608	1.37	7260	2315	787	469	809	----	1607	1334	1304	56.44	57.08	------	-----	4226	27.8	1779	-----	.0114	1.232
173		.609	618	1.37	7260	2615	794	469	816	3678	1700	1437	1394	56.75	57.48	.8535	2.559	4118	26.7	1882	61.42	.0128	1.220
174		.616	604	1.37	7260	2780	780	468	820	3699	1767	1482	1456	55.75	56.52	.8615	2.496	4042	26.0	1960	61.31	.0139	1.214
175		.579	622	1.37	7260	3015	781	469	824	3794	1840	1559	1529	55.57	56.41	.8553	2.434	3969	25.4	2037	60.93	.0151	1.203
176		.619	616	1.37	6897	1890	797	467	769	3331	1430	1226	1160	56.49	57.02	.8227	2.717	4236	27.2	1589	61.35	.0093	1.233
177		.621	607	1.37	6897	2350	787	467	788	3493	1604	1388	1319	55.68	56.33	.8482	2.517	4019	26.1	1782	61.40	.0117	1.216
178		.628	604	1.37	6897	2590	788	467	795	3606	1685	1471	1398	55.67	56.39	.8418	2.451	3928	25.3	1872	61.17	.0129	1.205
179		.629	610	1.37	6897	2875	796	466	801	3726	1777	1568	1484	56.27	57.07	.8513	2.376	3832	24.7	1978	61.63	.0142	1.197
180		.618	620	1.37	6897	3295	802	466	811	3903	1897	1697	1602	56.39	57.31	.8433	2.300	3718	24.1	2111	61.21	.0162	1.184
181		.616	612	1.37	6353	1535	---	466	730	2946	1300	1104	1059	52.44	52.87	.8071	2.668	4083	26.0	1447	61.12	.0081	1.228
182		.622	605	1.37	6353	1695	---	468	741	3017	1377	1174	1135	51.70	52.17	.8009	2.570	3973	25.4	1527	60.71	.0091	1.213
183		.629	605	1.37	6353	1890	---	467	747	3114	1463	1255	1217	51.91	52.44	.8013	2.481	3864	24.8	1625	61.05	.0101	1.202
184		.634	605	1.37	6353	2080	---	467	751	3186	1533	1326	1280	52.09	52.67	.8176	2.403	3782	24.0	1703	61.44	.0111	1.198
185		.627	612	1.37	6353	2215	---	466	750	3255	1570	1371	1322	52.43	53.05	.7976	2.374	3739	23.6	1747	61.36	.0117	1.188
186		.624	605	1.37	5808	1136	---	464	686	2459	1153	953	943	46.09	46.41	.8050	2.580	3946	24.4	1290	60.30	.0068	1.223
187		.629	603	1.37	5808	1305	---	466	695	2524	1255	1027	1038	45.92	46.28	.8102	2.458	3796	23.8	1397	61.25	.0079	1.209
188		.625	605	1.37	5808	1479	---	466	702	2607	1323	1095	1111	45.66	46.07	.7842	2.381	3702	22.7	1472	60.75	.0090	1.191
189		.634	609	1.37	5808	1602	---	464	704	2660	1380	1151	1171	46.31	46.76	.7718	2.311	3632	22.2	1544	57.95	.0096	1.178
190		.630	605	1.37	5808	1720	---	463	709	2702	1440	1185	1224	45.69	46.17	.7796	2.280	3559	22.1	1614	61.47	.0105	1.176
191		.619	608	1.37	4719	717	787	463	614	1615	987	753	841	33.07	33.27	.7792	2.145	3452	19.8	1106	60.63	.0060	1.174
192		.625	609	1.37	4719	743	793	463	614	1628	1003	768	857	33.31	33.52	.7790	2.120	3425	19.5	1124	61.12	.0062	1.170
193		.647	605	1.37	4719	851	801	464	619	1692	1067	829	920	33.24	33.48	.7794	2.041	3328	18.4	1194	60.67	.0071	1.160
194		.626	603	1.37	4719	917	785	465	625	1698	1150	862	995	32.14	32.39	.8072	1.970	3212	18.0	1282	60.86	.0079	1.156
195		.650	603	1.37	4719	1050	801	462	627	1790	1200	930	1083	32.09	32.38	.6094	1.925	3150	13.3	1349	59.07	.0091	1.108
196		.626	596	1.37	3630	588	776	462	546	1083	820	658	738	23.71	23.87	.7704	1.646	2904	12.8	922	58.93	.0069	1.111
197		.616	605	1.37	3630	617	781	463	548	1110	850	677	767	23.46	23.63	.7597	1.640	2854	13.0	953	57.96	.0073	1.108
198		.625	597	1.37	3630	655	777	463	551	1138	917	711	834	22.93	23.11	.7436	1.601	2752	12.1	1028	57.58	.0079	1.100
199		.633	610	1.37	3630	673	798	462	553	1179	945	741	857	23.29	23.58	.7752	1.591	2713	12.3	1062	57.56	.0080	1.103
200		.625	608	1.67	7260	2245	791	456	783	3468	1530	1287	1239	57.52	58.14	.8435	2.695	4324	27.7	1741	62.26	.0108	1.235
201		.616	612	1.67	7260	2375	791	459	787	3526	1590	1337	1302	57.23	57.89	.8239	2.637	4246	26.7	1797	62.26	.0115	1.221
202		.623	610	1.67	7260	2500	793	459	790	3574	1650	1384	1359	57.35	58.04	.8239	2.582	4172	26.1	1865	62.80	.0121	1.214
203		.627	608	1.67	7260	2625	792	458	792	3622	1650	1430	1359	57.39	58.12	.8416	2.533	4175	26.1	1868	62.04	.0127	1.214
204		.621	610	1.67	7260	2785	791	458	796	3682	1720	1471	1427	57.16	57.93	.8260	2.503	4097	25.4	1947	62.25	.0135	1.205
205		.623	607	1.67	7260	3080	789	460	806	3744	1810	1553	1507	56.81	57.67	.8536	2.411	4000	25.2	2042	62.64	.0151	1.201
206		.623	608	1.67	6897	1995	790	460	758	----	1443	1238	1178	56.40	56.95	------	-----	4222	26.6	1628	-----	.0098	1.225
207		.623	608	1.67	6897	2270	790	460	766	3407	1548	1334	1277	56.38	57.01	.8167	2.554	4086	25.6	1746	62.53	.0112	1.212
208		.624	608	1.67	6897	2560	790	459	773	3523	1643	1441	1370	56.50	57.21	.8187	2.445	3974	24.6	1857	62.70	.0126	1.199
209		.619	614	1.37	6897	2845	795	458	780	3630	1730	1533	1448	56.75	57.54	.8393	2.368	3882	24.0	1958	62.85	.0139	1.195
210		.625	608	1.67	6897	3015	791	459	787	3724	1793	1601	1506	56.28	57.12	.8449	2.326	3817	23.9	2026	62.07	.0149	1.191
211		.621	610	1.67	6353	1625	791	459	721	2943	1270	1132	1031	52.86	53.31	.8353	2.600	4128	26.3	1435	60.95	.0085	1.232
212		.625	610	1.67	6353	1880	794	462	733	3045	1428	1234	1185	52.64	53.16	.8112	2.468	3907	24.6	1605	62.55	.0099	1.205
213		.621	608	1.67	6353	2100	788	459	736	3130	1500	1315	1257	52.28	52.86	.8088	2.380	3820	23.9	1695	62.08	.0112	1.193
214		.625	608	1.67	6353	2220	791	459	739	3172	1543	1357	1296	52.42	53.04	.8198	2.338	3768	23.6	1744	62.41	.0118	1.191
215		.621	609	1.67	6353	2410	789	459	745	3263	1620	1426	1365	52.16	52.83	.8306	2.288	3685	22.9	1831	62.04	.0128	1.187
216		.625	610	1.67	5808	1209	794	462	681	2432	1150	971	939	46.70	47.04	.8333	2.505	3954	24.6	1293	61.67	.0072	1.225
217		.625	609	1.67	5808	1301	792	461	684	2476	1200	1009	987	46.56	46.92	.8267	2.454	3878	24.0	1351	61.84	.0078	1.216
218		.624	609	1.67	5808	1427	792	461	686	2532	1267	1061	1057	46.45	46.85	.8024	2.386	3779	23.2	1427	62.14	.0085	1.199
219		.624	610	1.67	5808	1550	794	460	690	2577	1330	1112	1123	46.52	46.95	.7823	2.317	3693	22.2	1500	62.76	.0093	1.184
220		.622	610	1.67	5808	1681	792	460	695	2629	1390	1157	1179	46.22	46.69	.7865	2.272	3617	21.7	1568	62.70	.0101	1.179
221		.622	610	1.67	4719	790	792	457	607	1632	995	773	850	33.51	33.73	.7842	2.110	3442	19.0	1130	61.08	.0065	1.171
222		.627	605	1.67	4719	800	788	457	608	1602	1010	777	866	33.35	33.57	.7922	2.062	3415	18.7	1147	62.43	.0067	1.166
223		.628	601	1.67	4719	850	784	457	610	1607	1043	797	900	33.15	33.39	.7870	2.016	3364	18.2	1185	62.92	.0071	1.159

TABLE I. - VARIABLE-AREA TURBINE PERFORMANCE - Concluded

Run	Altitude (ft)	M_0	p_0 (lb/sq ft)	Turbine nozzle area (sq ft)	N (rpm)	W_f (lb/hr)	P_2 (lb/sq ft)	T_2 (°R)	T_4 (°R)	P_5 (lb/sq ft)	T_5 (°R)	P_6 (lb/sq ft)	T_6 (°R)	$W_{a,1}$ (lb/sec)	$W_{g,5}$ (lb/sec)	η_t	P_5/P_6	$\frac{N}{\sqrt{\theta_5}}$ (rpm)	$\frac{\Delta H_t}{\theta_5}$ (Btu/lb)	$\frac{T_5}{\theta_2}$ (°R)	$\frac{W_{g,5}\sqrt{\theta_5}}{\delta_5}\left(\frac{\gamma_5}{1.4}\right)$ (lb/sec)	$\frac{W_f}{W_{a,1}(3600)}$	$\frac{T_5}{T_6}$
224	30,000	0.618	604	1.67	4719	960	781	458	615	1673	1130	856	988	32.22	32.49	0.7604	1.954	3239	16.8	1279	61.43	0.0083	1.144
225		.642	603	1.67	4719	1160	795	457	623	1816	1263	960	1121	31.65	31.97	.7252	1.892	3074	16.0	1435	59.08	.0102	1.127
226		.624	608	1.67	3630	610	791	459	543	1097	827	---	753	24.24	24.41	------	-----	2892	12.0	935	59.74	.0070	1.098
227		.619	610	1.67	3630	620	790	459	543	1102	840	681	765	24.22	24.39	.7116	1.618	2870	11.8	949	59.92	.0071	1.096
228		.629	607	1.67	3630	640	792	458	542	1111	855	691	782	24.31	24.49	.6904	1.608	2847	11.6	968	60.21	.0073	1.093
229		.621	608	1.67	3630	670	788	458	544	1129	900	714	825	23.79	23.98	.6994	1.581	2777	11.0	1019	59.61	.0078	1.091
230		.625	609	1.67	3630	735	792	459	549	1174	975	746	893	23.10	23.30	.7213	1.574	2673	11.3	1102	58.10	.0088	1.092
231	40,000	0.341	376	1.20	7260	1252	408	436	680	1997	1467	695	1251	30.69	31.04	.6167	2.873	4408	21.4	1746	56.47	.0113	1.173
232		.327	375	1.20	7260	1370	404	436	786	2045	1643	728	1335	30.20	30.58	.8131	2.809	4182	27.9	1955	57.76	.0126	1.231
233		.344	376	1.20	7260	1439	408	435	---	2096	----	747	1352	30.52	30.92	------	2.806	----	----	----	------	.0131	-----
234		.312	378	1.20	6897	1170	405	434	697	1911	1430	666	1201	30.11	30.44	.6688	2.869	4239	23.4	1712	57.09	.0108	1.191
235		.341	395	1.20	6897	1651	428	434	707	2235	1680	855	1442	31.41	31.87	.6612	2.614	3934	20.8	2011	55.76	.0146	1.165
236		.344	375	1.20	6353	948	407	433	673	1699	1298	610	1082	28.62	28.88	.7000	2.785	4088	23.6	1556	57.84	.0092	1.200
237		.344	375	1.20	6353	1197	407	434	668	1823	1468	695	1264	28.58	28.91	.6301	2.623	3857	20.7	1757	57.66	.0116	1.161
238		.341	375	1.20	5808	791	406	435	670	1436	1248	543	1028	24.75	24.97	.7722	2.645	3804	24.0	1488	57.95	.0089	1.214
239		.341	376	1.20	5808	970	408	434	665	1489	1415	607	1207	24.23	24.50	.7050	2.453	3590	21.0	1694	58.64	.0111	1.172
240		.340	375	1.30	7260	1331	406	442	677	1942	1515	697	1306	30.59	30.96	.5969	2.786	4345	19.7	1780	58.90	.0121	1.160
241		.327	391	1.30	7260	1445	421	437	667	2047	1542	752	1340	31.67	32.07	.5802	2.722	4311	19.4	1832	58.48	.0127	1.151
242		.303	392	1.30	7260	1562	418	440	670	2095	1622	793	1420	31.32	31.75	.5722	2.642	4211	18.5	1912	58.11	.0139	1.142
243		.334	386	1.30	7260	1717	417	441	740	2146	1775	834	1510	30.99	31.47	.7126	2.573	4038	22.3	2089	59.01	.0154	1.175
244		.283	387	1.30	6897	1230	409	435	669	1891	1442	689	1239	30.40	30.74	.6122	2.745	4224	20.6	1719	58.53	.0112	1.164
245		.326	403	1.30	6897	1361	434	439	676	2029	1500	765	1289	32.10	32.48	.6326	2.652	4147	20.6	1773	58.87	.0118	1.164
246		.326	394	1.30	6897	1520	424	437	671	2061	1608	808	1398	31.44	31.86	.6190	2.551	4015	19.0	1910	58.96	.0134	1.150
247		.311	383	1.30	6897	1622	409	435	672	2053	1690	830	1481	30.21	30.66	.6100	2.474	3925	18.1	2014	58.52	.0149	1.141
248		.327	372	1.30	6353	969	401	436	671	1643	1322	609	1108	28.29	28.56	.7030	2.698	4052	22.8	1573	59.75	.0095	1.193
249		.351	379	1.30	6353	1100	413	435	672	1742	1398	670	1190	28.99	29.30	.6742	2.600	3948	21.6	1666	59.56	.0105	1.175
250		.381	368	1.30	5808	804	407	435	661	1400	1240	546	1030	25.18	25.40	.7617	2.564	3816	23.3	1478	60.28	.0089	1.204
251		.338	374	1.30	5808	970	405	435	669	1460	1402	613	1200	24.22	24.49	.7120	2.382	3603	21.2	1671	59.51	.0111	1.168
252		.341	374	1.67	7260	1423	405	436	776	1884	1637	714	1336	30.72	31.12	.8424	2.639	4192	27.0	1948	63.64	.0129	1.225
253		.348	373	1.67	7260	1620	405	438	785	1996	1797	799	1493	30.45	30.90	.8306	2.498	4013	25.4	2131	62.71	.0148	1.204
254		.338	375	1.67	7260	1750	406	437	791	2041	1870	834	1562	30.52	31.01	.8343	2.447	3941	25.0	2222	62.87	.0159	1.197
255		.257	389	1.67	6897	1330	407	436	747	1807	1550	692	1278	30.25	30.62	.8039	2.611	4083	25.9	1845	63.39	.0122	1.213
256		.341	375	1.67	6897	1562	407	438	765	1923	1755	790	1469	30.13	30.56	.8195	2.434	3855	24.4	2081	63.50	.0144	1.195
257		.338	382	1.67	6897	1725	414	439	771	2023	1823	838	1539	30.60	31.08	.7957	2.414	3787	23.8	2155	62.70	.0157	1.185
258		.338	374	1.67	6353	1052	405	439	670	1624	1370	639	1166	28.48	28.77	.6878	2.541	3983	[illegible]	1619	62.03	.0103	1.175
259		.329	377	1.67	6353	1267	406	437	671	1704	1515	710	1309	28.46	28.81	.6776	2.400	3802	[illegible]	1300	62.50	.0124	1.157
260		.361	373	1.67	6353	1391	408	438	726	1756	1633	761	1385	28.54	28.93	.7953	2.307	3674	22.7	1937	63.38	.0135	1.179
261		.338	373	1.67	5808	854	404	439	663	1362	1273	558	1071	25.09	25.33	.7532	2.441	3771	22.3	1505	62.66	.0095	1.189
262		.338	373	1.67	5808	1229	404	438	670	1485	1623	694	1420	23.67	24.01	.7144	2.140	3367	18.5	1925	62.03	.0144	1.143
263	44,000	0.107	303	1.30	7260	1098	306	453	809	1520	1720	563	1403	22.72	23.03	0.8339	2.700	4095	27.4	1973	59.93	0.0134	1.226
264		.118	297	1.30	7260	1180	300	453	816	1528	1803	579	1485	22.30	22.63	.8228	2.639	4009	26.5	2068	60.06	.0147	1.214
265		.130	295	1.30	7260	1370	297	452	822	1589	1930	624	1612	22.23	22.61	.8078	2.546	3854	25.2	2214	59.87	.0171	1.197
266		.125	312	1.30	6897	970	316	454	781	1472	1560	535	1271	22.80	23.07	.8124	2.751	[illegible]	27.2	1783	58.82	.0118	1.227
267		.152	312	1.30	6897	1072	317	454	787	1500	1655	565	1360	22.91	23.21	.8142	2.655	[illegible]	[illegible]	1892	59.96	.0130	1.217
268		.152	312	1.30	6897	1126	317	454	792	1526	1697	582	1400	22.91	23.22	.8128	2.622	[illegible]	26.1	1940	59.77	.0137	1.212
269		.152	312	1.30	6897	1172	317	454	796	1571	1740	612	1440	22.91	23.24	.8202	2.567	[illegible]	25.8	1909	58.85	.0142	1.208
270		.152	308	1.30	6353	844	313	448	730	----	1427	428	1177	21.97	22.20	------	-----	3910	25.3	1652	-----	.0107	1.212
271		.125	303	1.30	6353	870	306	444	734	----	1480	447	1229	21.68	21.92	------	-----	[illegible]	25.3	1730	-----	.0111	1.204
272		.136	315	1.67	7260	1319	319	446	799	1560	1810	574	1502	23.93	24.30	.7719	2.718	4000	25.5	2107	63.39	.0153	1.205
273		.160	306	1.67	7260	1242	311	446	787	1501	1770	503	1472	23.42	23.77	.7046	2.984	4042	25.1	2060	63.62	.0147	1.202
274		.169	308	1.67	6897	1115	314	445	673	1443	1555	558	1359	22.97	23.28	.5862	2.586	4081	18.9	1813	60.52	.0135	1.144
275		.141	308	1.67	6897	1130	312	440	695	1446	1607	568	1383	22.96	23.27	.6607	2.546	4017	20.7	1895	61.43	.0137	1.162
276		.184	310	1.67	6897	1184	317	440	681	1479	1610	587	1402	23.21	23.54	.6193	2.520	4015	19.3	1898	60.79	.0142	1.148
277		.160	311	1.67	6897	1313	317	440	673	1544	1733	637	1528	23.39	23.75	.5984	2.424	3879	17.7	2043	61.16	.0156	1.134
278		-----	304	1.67	6353	904	---	445	673	----	----	434	1230	-----	-----	-----	-----	----	----	----	-----	------	-----

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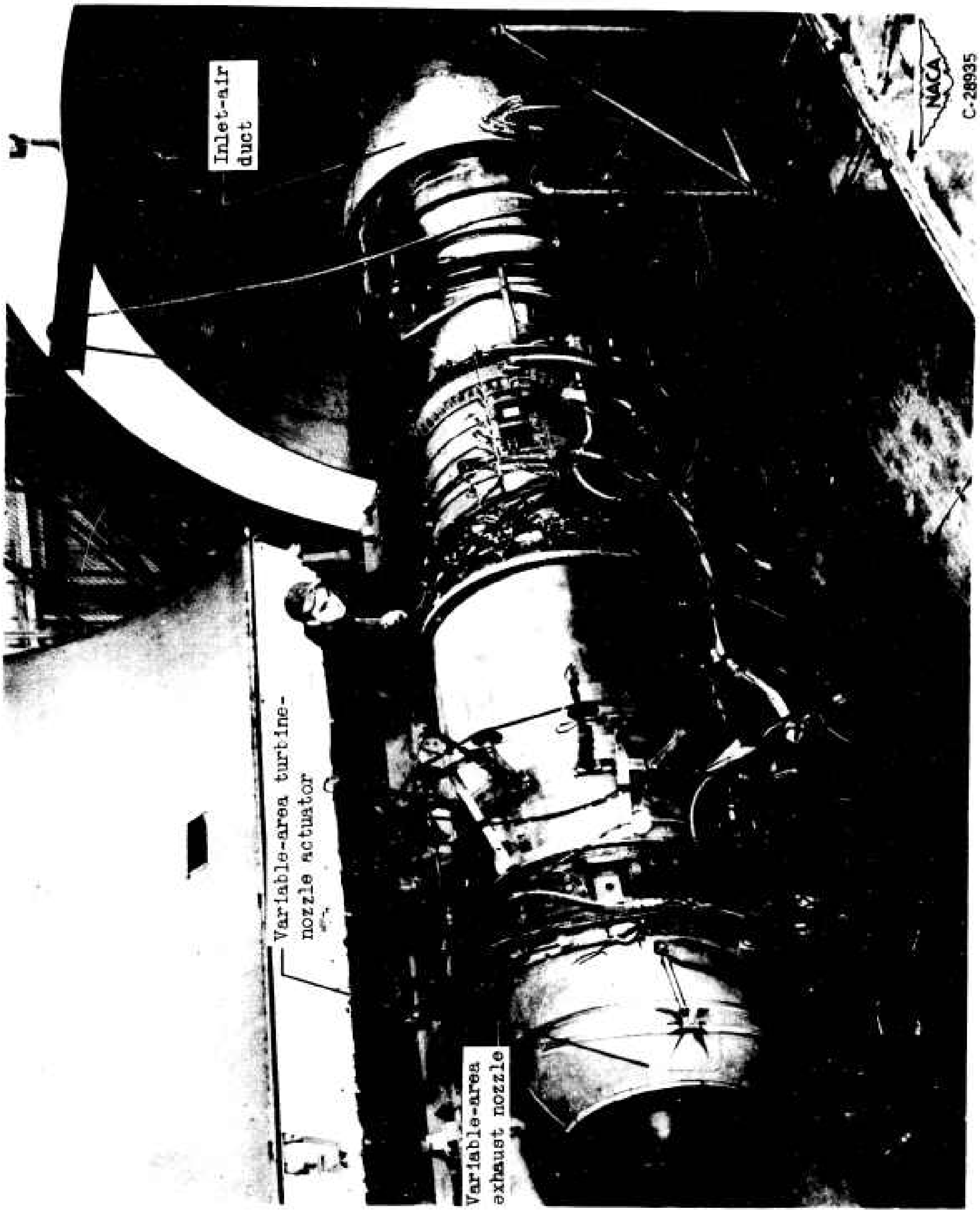
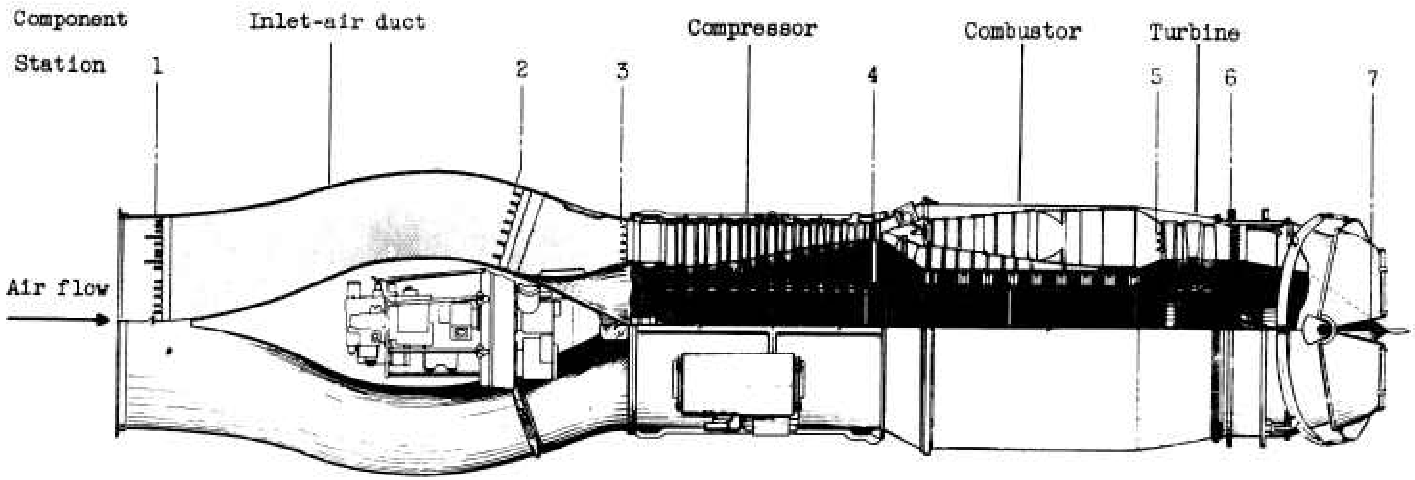


Figure 1. - Installation of turbojet engine in altiude wind tunnel.



Station	Location	Total pressure tubes	Static pressure tubes	Wall static pressure orifices	Thermo-couples
1	Inlet-air duct	29	12	4	10
2	Engine inlet	18	0	4	0
3	Compressor inlet	23	3	7	0
4	Compressor outlet	15	0	2	6
5	Turbine inlet	5	0	0	0
6	Turbine outlet	20	0	8	24
7	Exhaust-nozzle outlet	16	2	8	0

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Figure 2. - Top view of turbojet-engine installation showing stations at which instrumentation was installed

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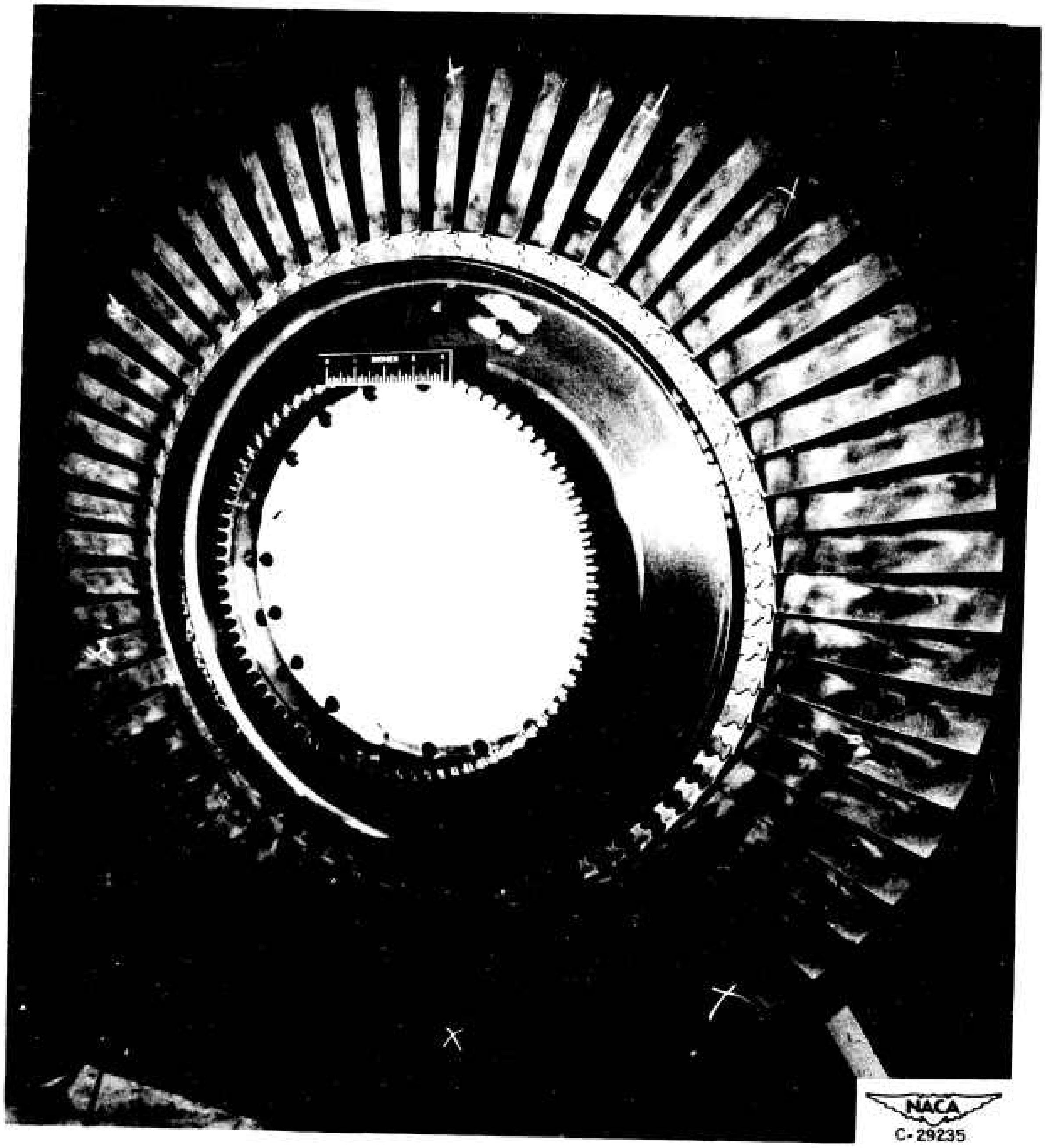

(a) First-stage turbine rotor.

Figure 3. - Photographs of turbine rotors.

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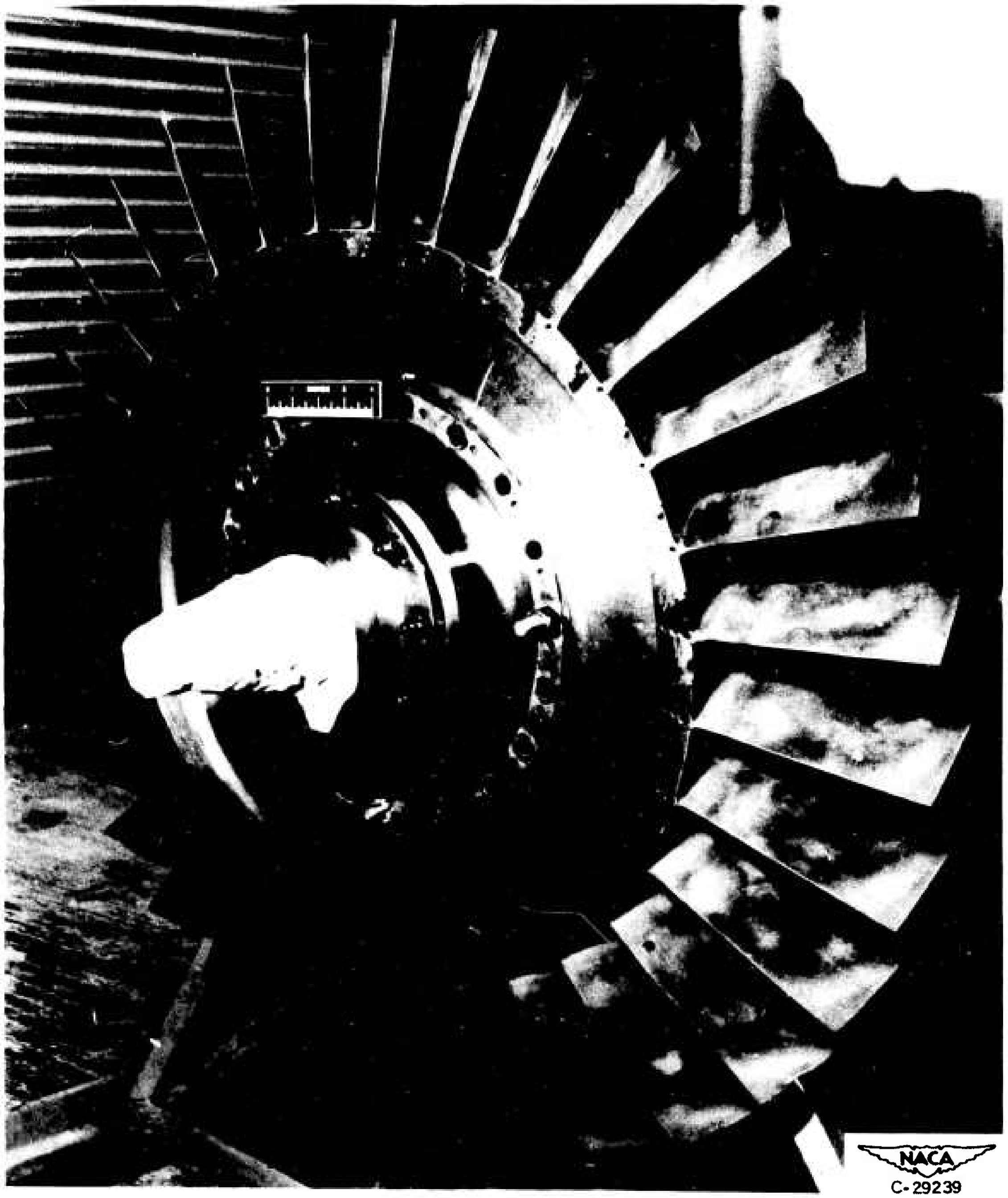
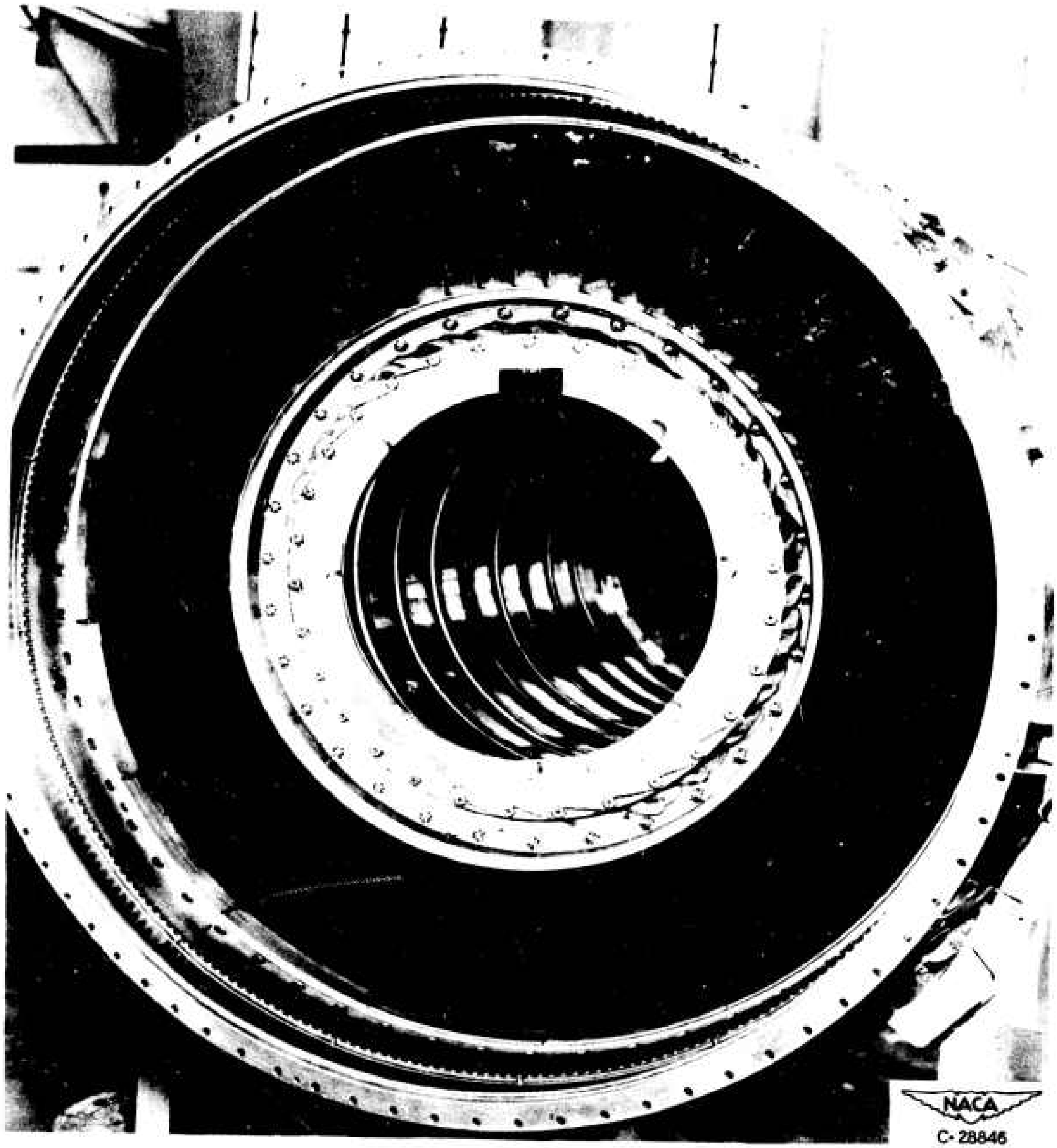


(b) Second-stage turbine rotor.

Figure 3. - Concluded. Photographs of turbine rotors.

2618



(a) Open.

Figure 4. - Photographs of variable-area turbine nozzles.

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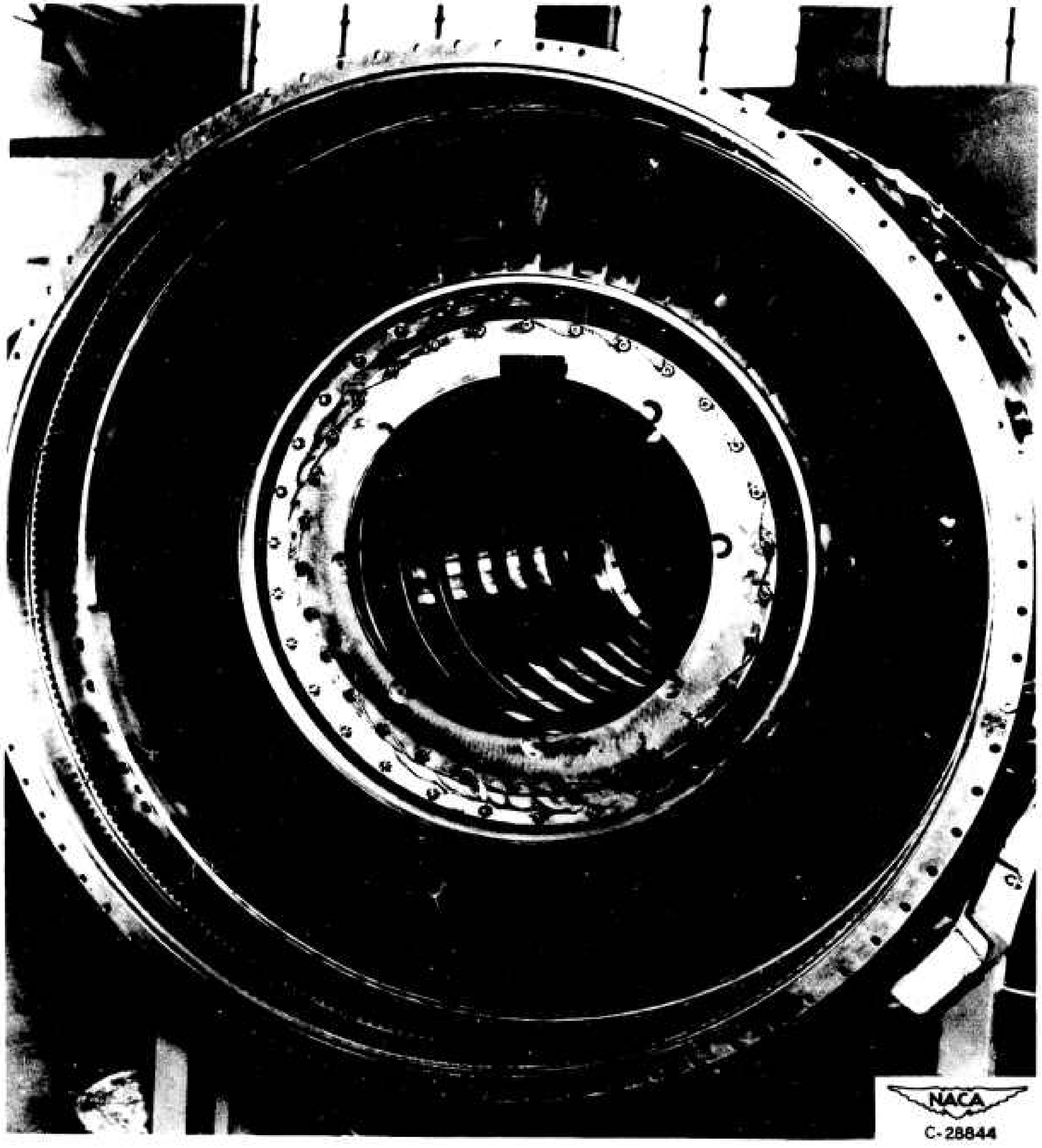

(b) Closed.

Figure 4. - Concluded. Photographs of variable-area turbine nozzles.

2618

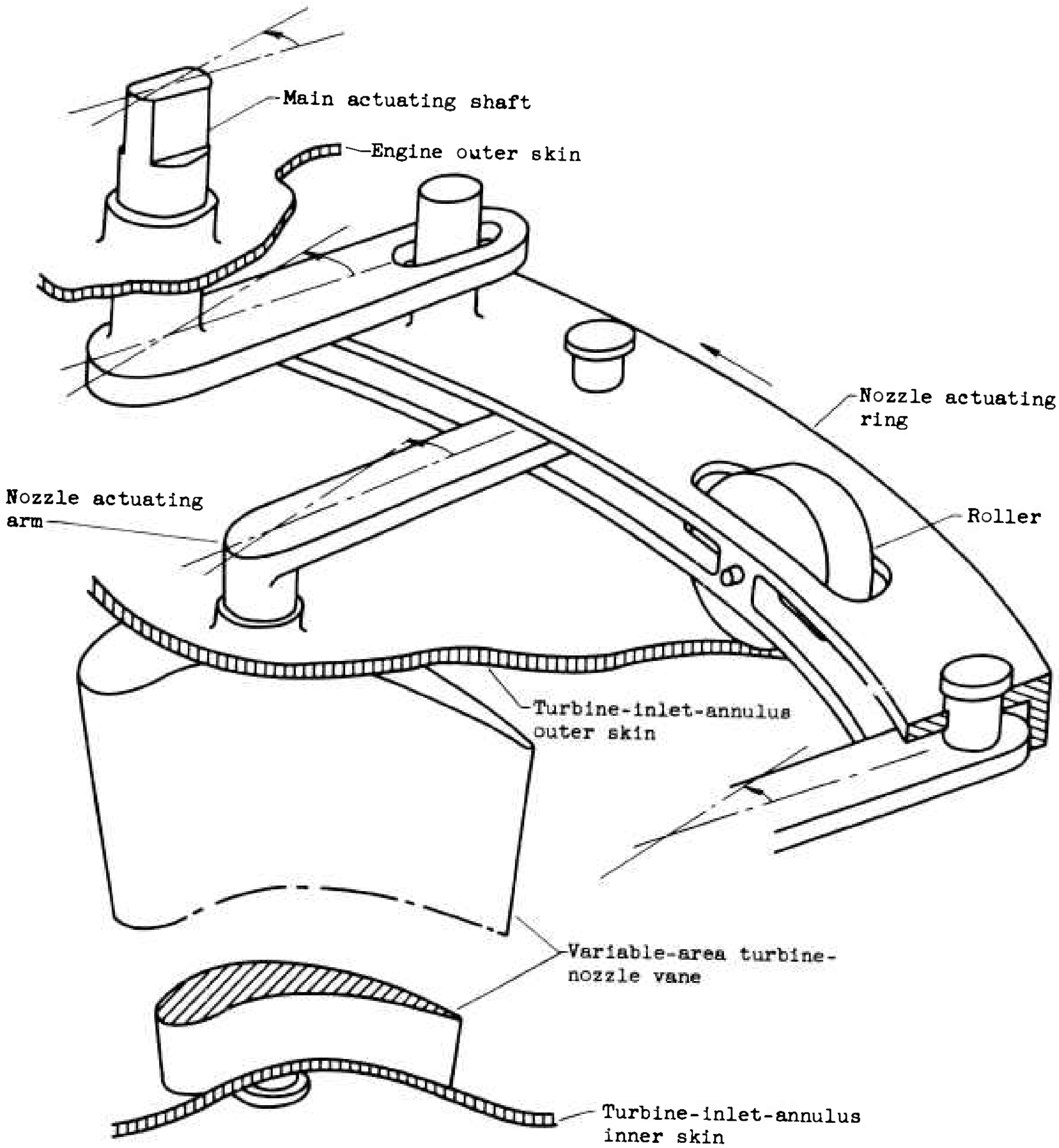

Figure 5. - Schematic sketch of variable-area turbine-nozzle actuating mechanism.

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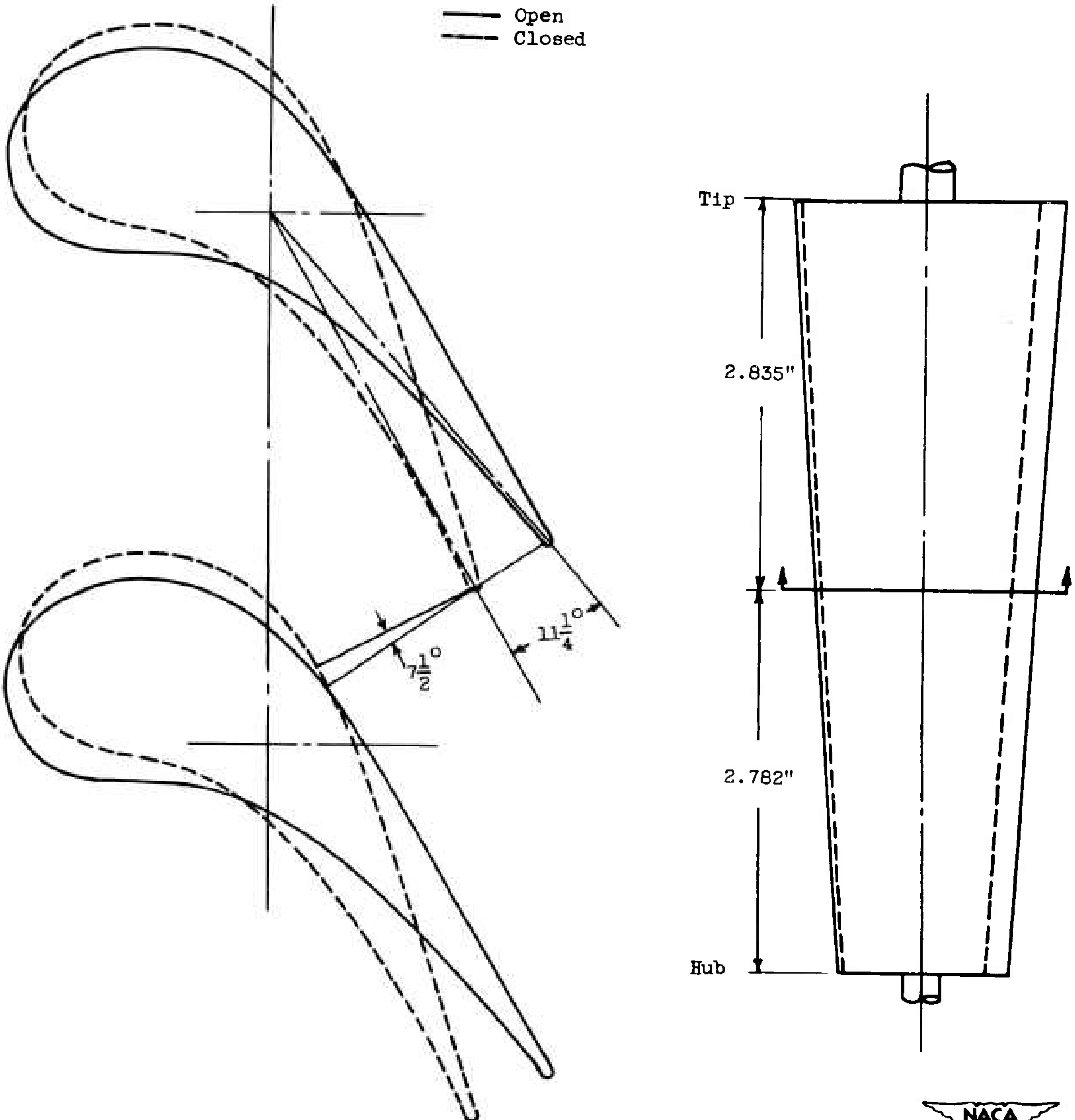

(a) Mid-vane cross-sections of two adjacent vanes ($2\frac{1}{2}$ times actual size).

(b) Side view of vane (actual size).

Figure 6. - Sketches of variable-area turbine-nozzle vanes in open and closed positions.

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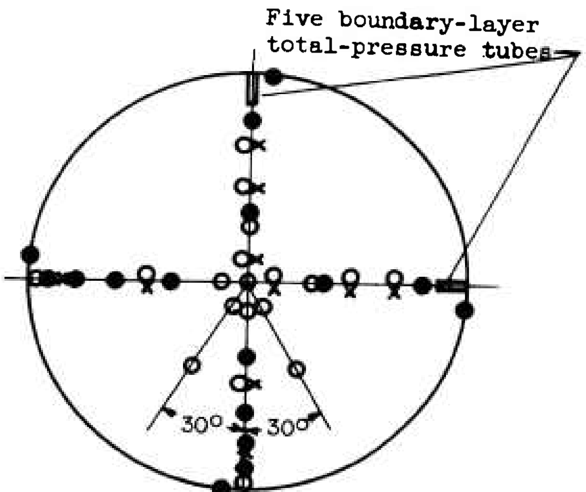
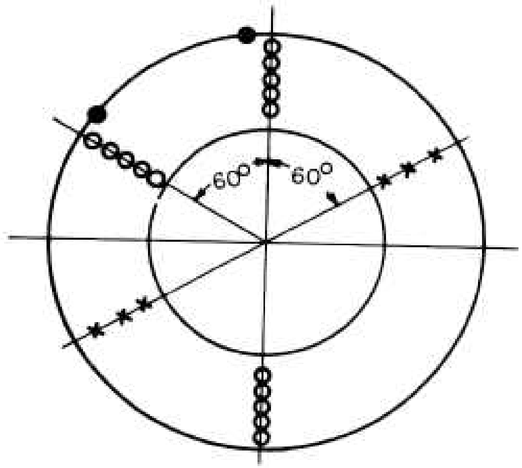
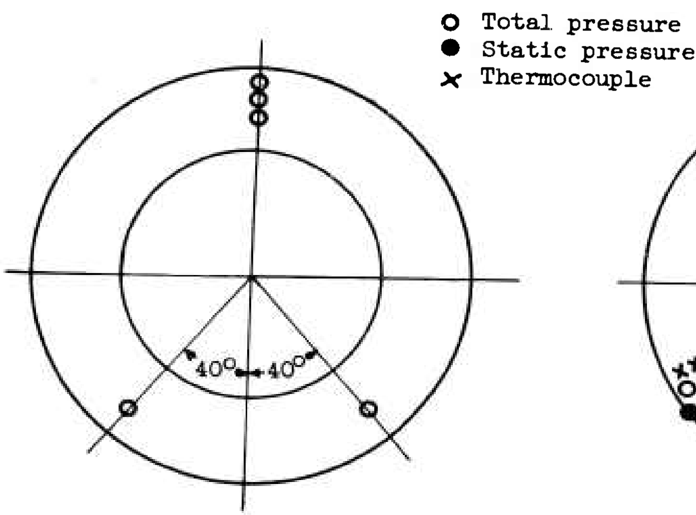


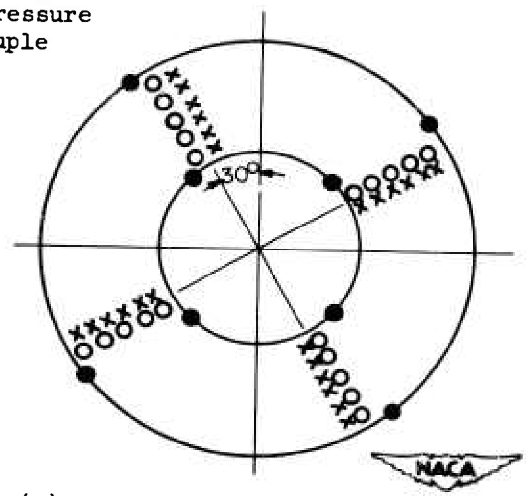
(a) Station 1, cowl inlet. Diameter, 34 inches: location, 6 inches downstream of cowl-inlet flange.



(b) Station 4, compressor outlet. Passage height, $3\frac{1}{8}$ inches; location, 1/2 inch downstream of trailing edge of fixed vanes.



(c) Station 5, turbine inlet. Passage height, $6\frac{3}{4}$ inches; location, $1\frac{3}{4}$ inches upstream of leading edge of first-stage turbine-nozzle diaphragm.



(d) Station 6, turbine outlet. Passage height, $5\frac{5}{8}$ inches; location, $3\frac{3}{8}$ inches downstream of trailing edge of turbine rotor.

Figure 7. - Location of instrumentation (view looking downstream).

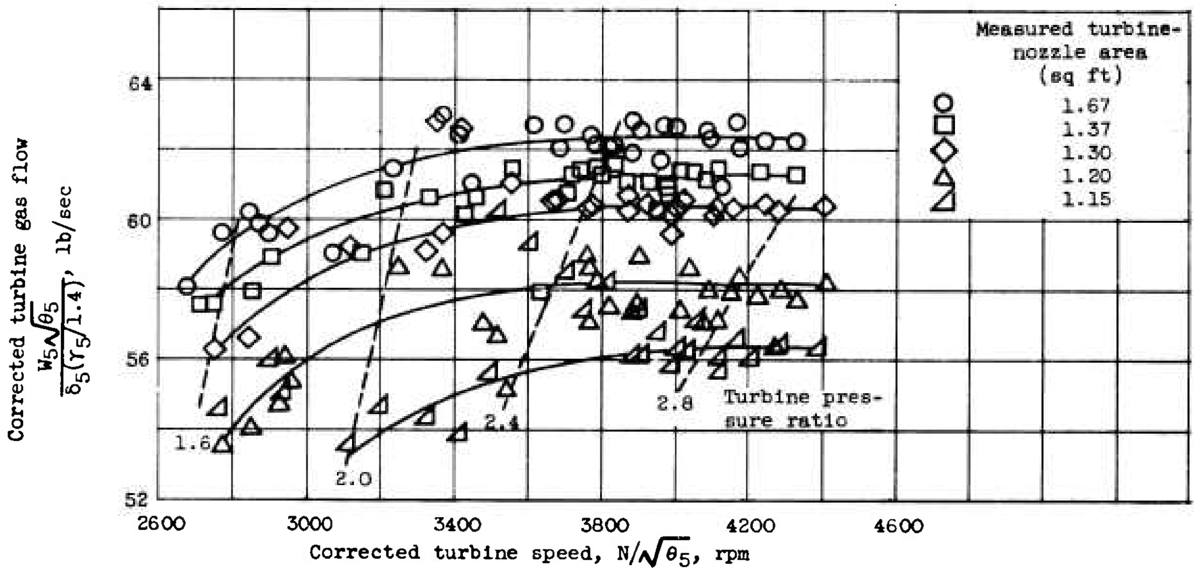


Figure 8. - Effect of turbine-nozzle area and corrected turbine speed on corrected turbine gas flow. Altitude, 30,000 feet; flight Mach number, 0.62.

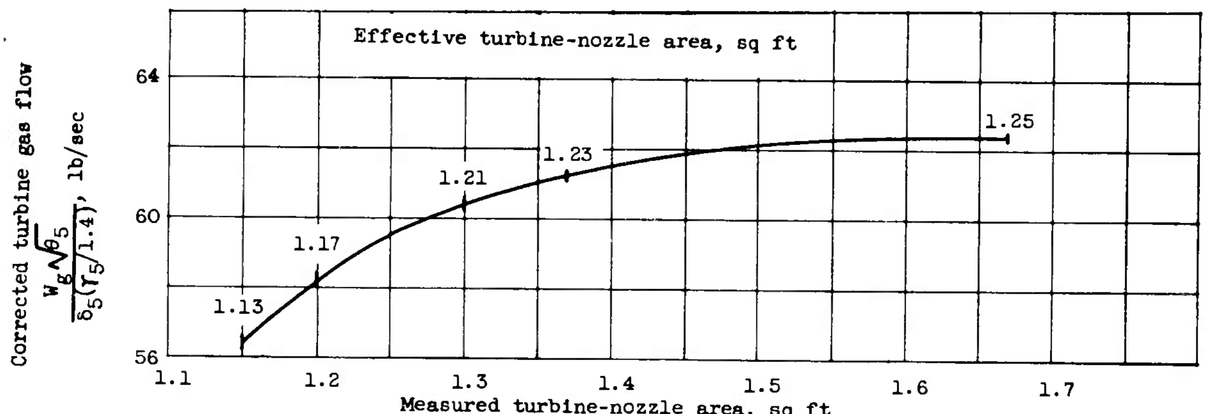


Figure 9. - Variation of maximum corrected turbine gas flow or effective turbine-nozzle area with measured turbine-nozzle area. Altitude 30,000 feet; flight Mach number, 0.62.

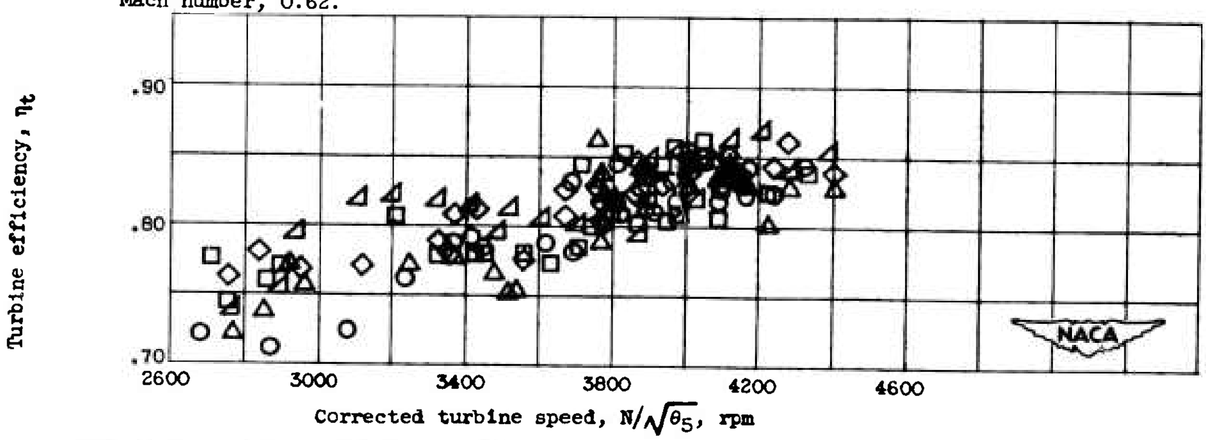


Figure 10. - Effect of turbine-nozzle area and corrected turbine speed on turbine efficiency. Altitude, 30,000 feet; flight Mach number, 0.62.

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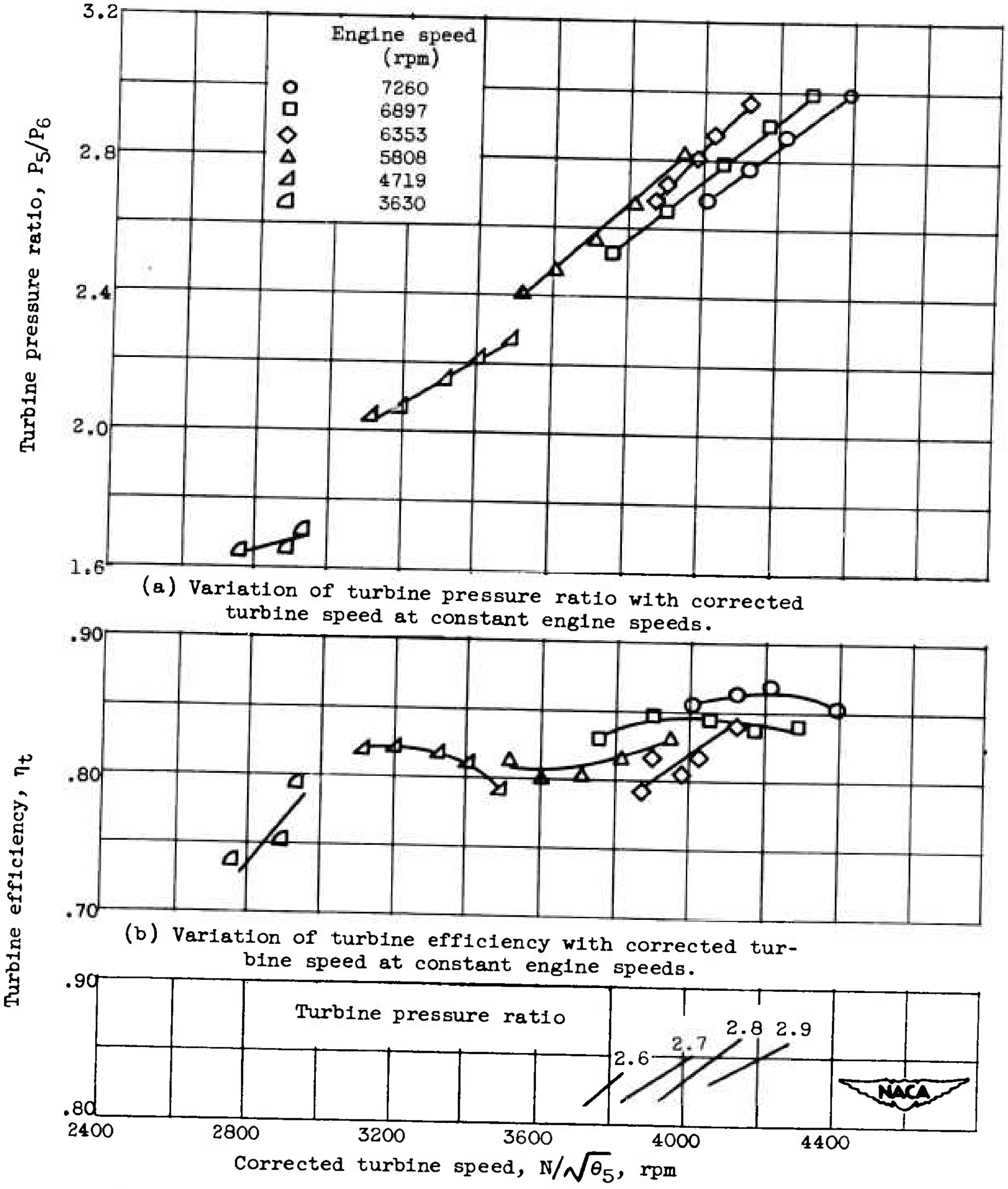
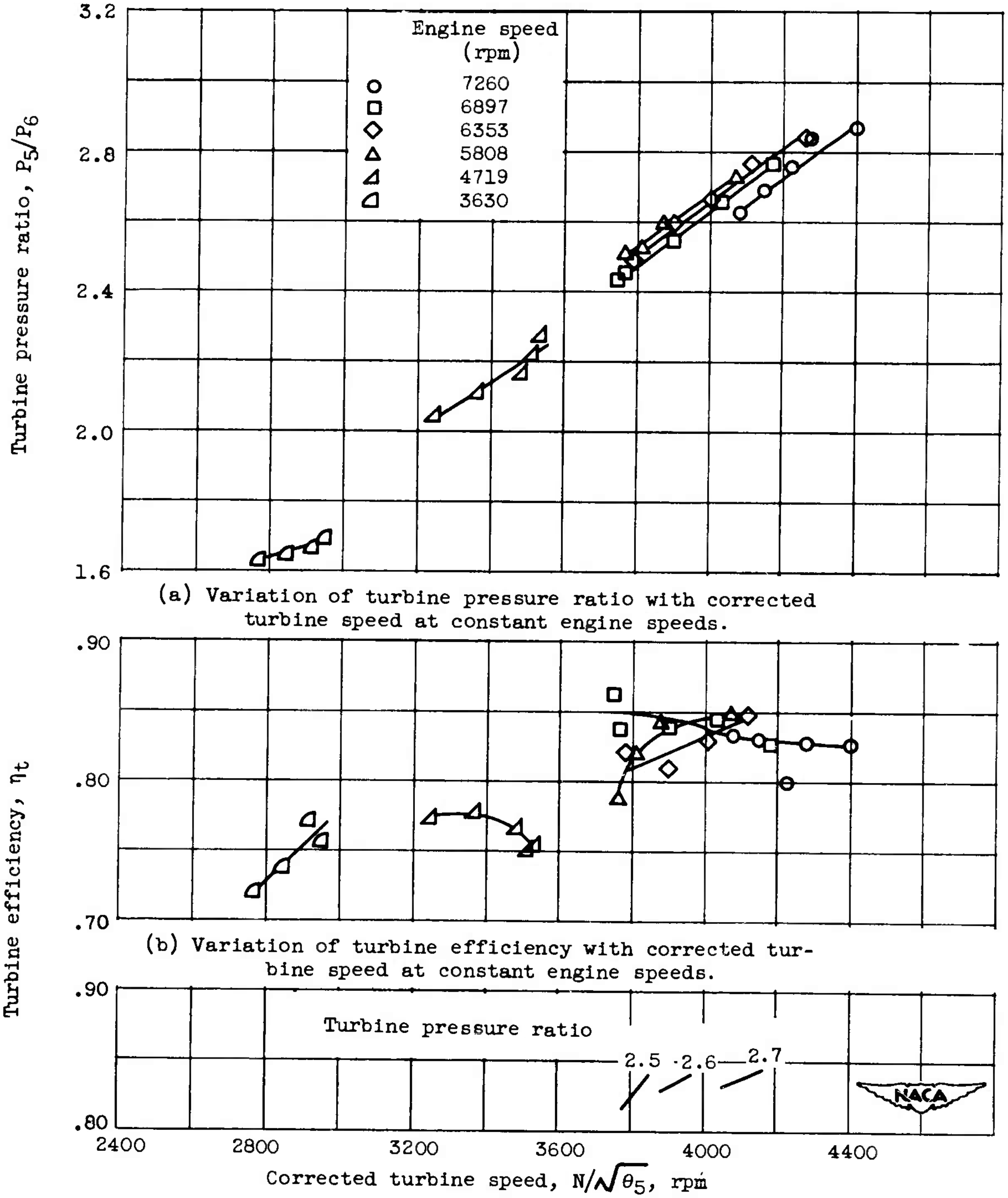


(a) Variation of turbine pressure ratio with corrected turbine speed at constant engine speeds.

(b) Variation of turbine efficiency with corrected turbine speed at constant engine speeds.

(c) Cross plots showing variation of turbine efficiency with corrected turbine speed at constant values of turbine pressure ratio.

Figure 11. - Effect of various parameters on turbine pressure ratio and turbine efficiency. Altitude, 30,000 feet; flight Mach number, 0.62; turbine nozzle area, 1.15 square feet.



(a) Variation of turbine pressure ratio with corrected turbine speed at constant engine speeds.

(b) Variation of turbine efficiency with corrected turbine speed at constant engine speeds.

(c) Cross plots showing variation of turbine efficiency with corrected turbine speed at constant values of turbine pressure ratio.

Figure 12. - Effect of various parameters on turbine pressure ratio and turbine efficiency. Altitude, 30,000 feet; flight Mach number, 0.62; turbine nozzle area, 1.20 square feet.

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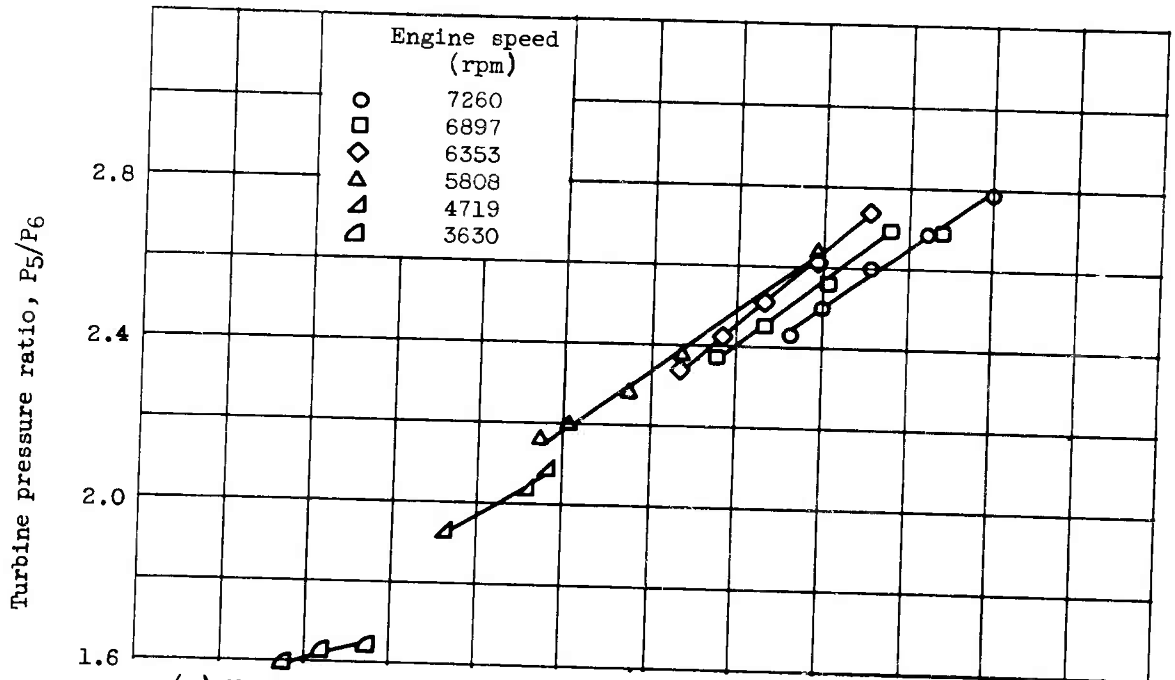
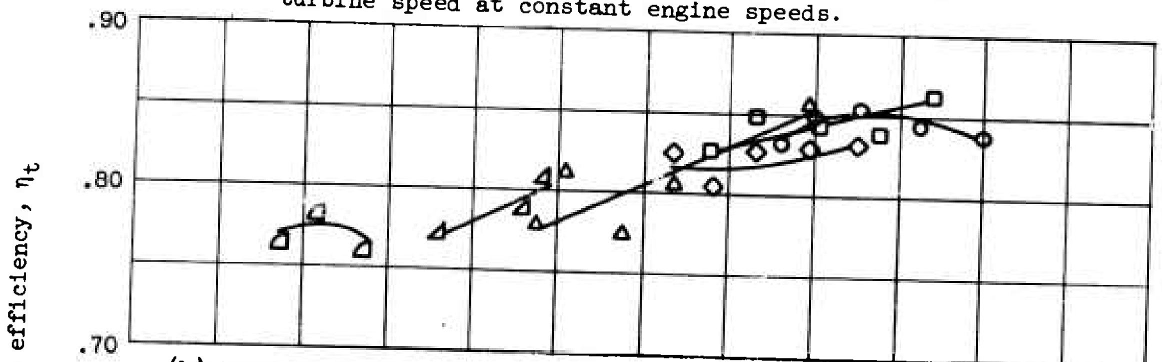
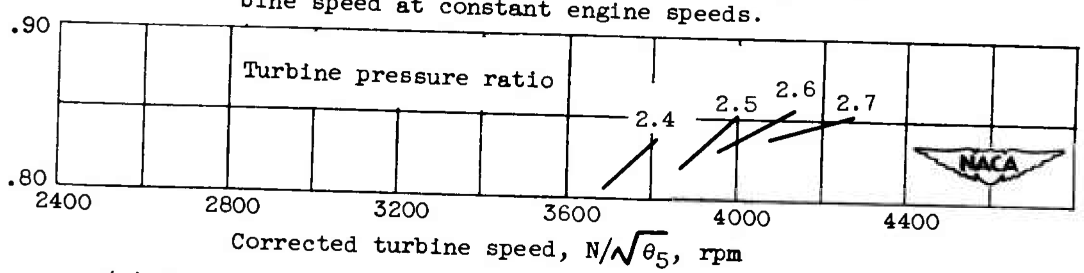


(a) Variation of turbine pressure ratio with corrected turbine speed at constant engine speeds.



(b) Variation of turbine efficiency with corrected turbine speed at constant engine speeds.



(c) Cross plots showing variation of turbine efficiency with corrected turbine speed at constant values of turbine pressure ratio.

Figure 13. - Effect of various parameters on turbine pressure ratio and turbine efficiency. Altitude, 30,000 feet; flight Mach number, 0.62; turbine nozzle area, 1.30 square feet.

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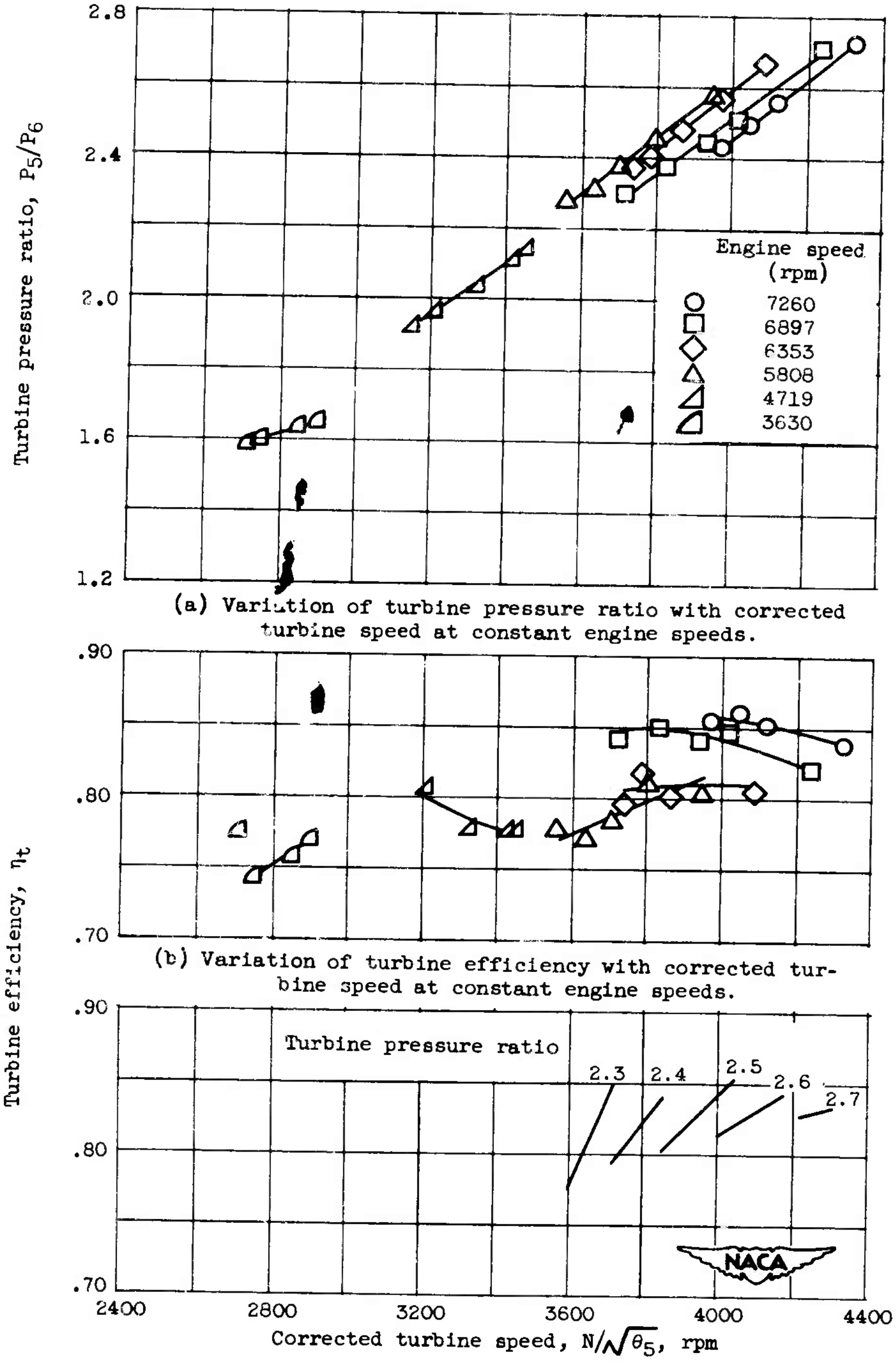

(a) Variation of turbine pressure ratio with corrected turbine speed at constant engine speeds.

(b) Variation of turbine efficiency with corrected turbine speed at constant engine speeds.

(c) Cross plots showing variation of turbine efficiency with corrected turbine speed at constant values of turbine pressure ratio.

Figure 14. - Effect of various parameters on turbine pressure ratio and turbine efficiency. Altitude, 30,000 feet; flight Mach number, 0.62; turbine nozzle area, 1.37 square feet.

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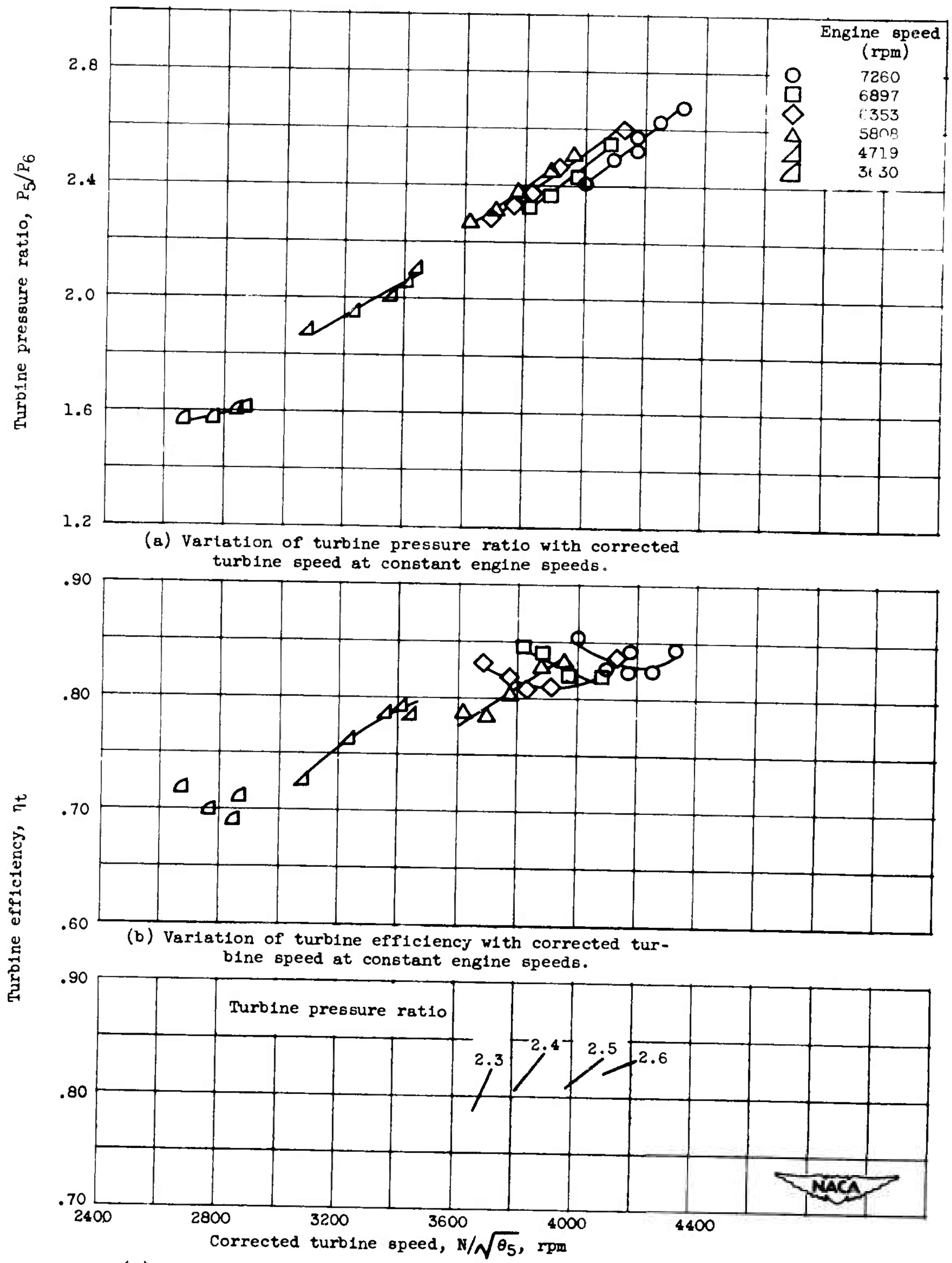

(a) Variation of turbine pressure ratio with corrected turbine speed at constant engine speeds.

(b) Variation of turbine efficiency with corrected turbine speed at constant engine speeds.

(c) Cross plots showing variation of turbine efficiency with corrected turbine speed at constant values of turbine pressure ratio.

Figure 15. - Effect of various parameters on turbine pressure ratio and turbine efficiency. Altitude, 30,000 feet; flight Mach number, 0.62; turbine nozzle area, 1.[illegible] square feet.

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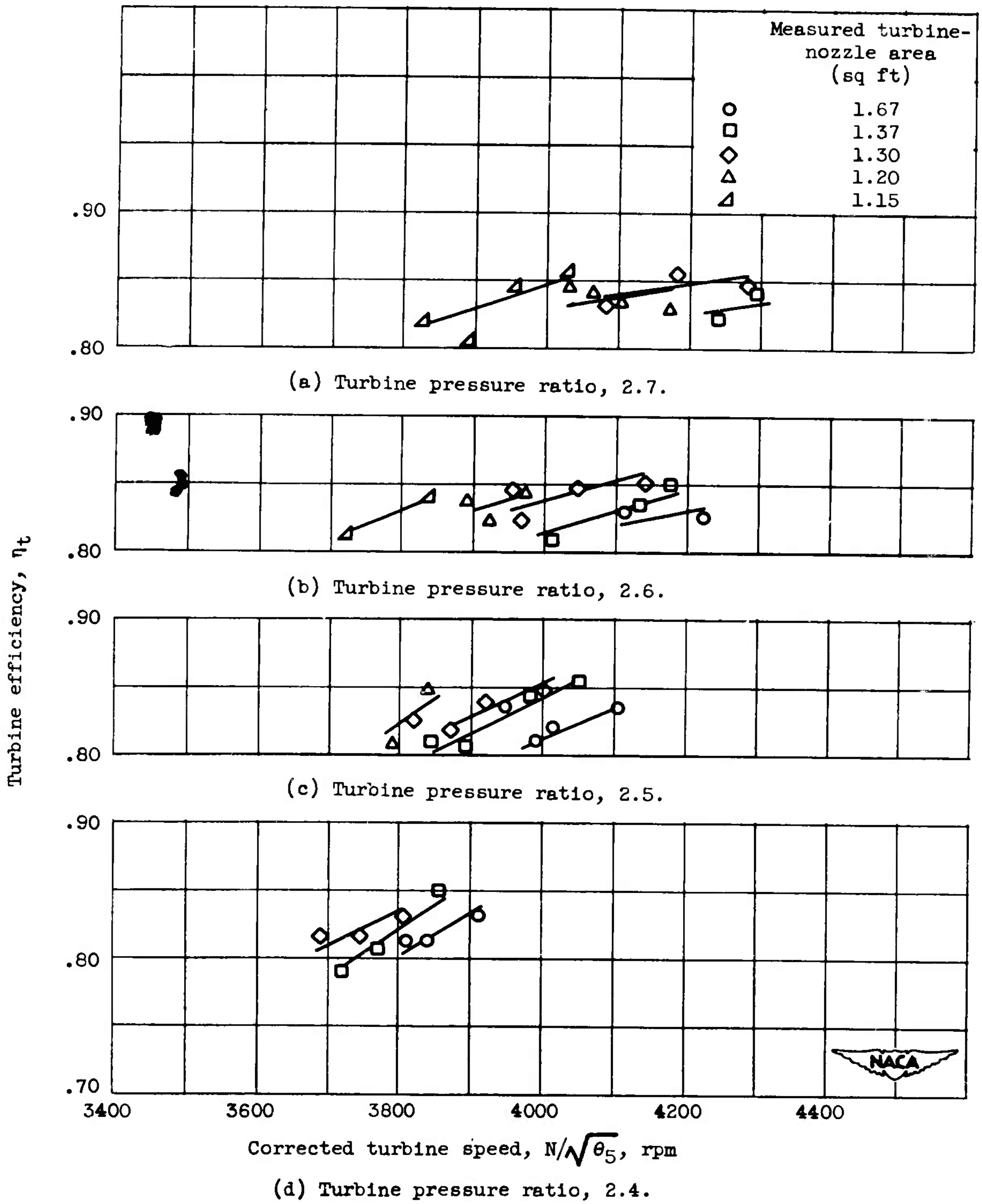

Figure 16. - Effect of turbine-nozzle area and corrected turbine speed on turbine efficiency at constant values of turbine pressure ratio. Altitude, 30,000 feet; flight Mach number, 0.62.

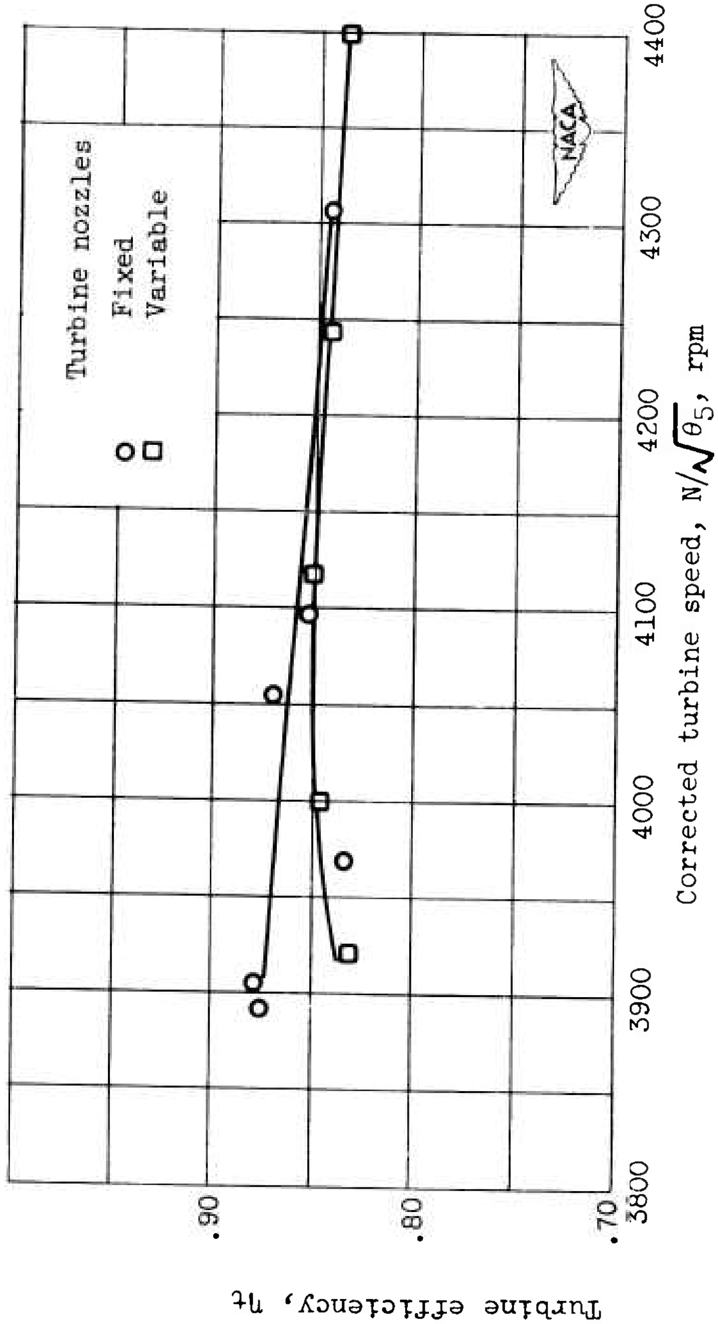

Figure 17. - Comparison of efficiencies obtained with fixed turbine nozzles and with variable-area turbine nozzles for an actual turbine-nozzle area of 1.30 square feet. Altitude, 30,000 feet; flight Mach number, 0.62; engine speed, 7260 rpm.

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CONFIDENTIAL

The performance of a two-stage turbine with variable-area first-stage turbine nozzles was determined in the NACA Lewis altitude wind tunnel over a range of simulated altitudes from 15,000 to 44,000 feet and engine speeds from 50 to 100 percent of rated speed. The variable-area turbine nozzles were found to be mechanically reliable and to have negligible leakage losses. Increasing the turbine-nozzle-throat area from 1.15 to 1.67 square feet increased the corrected turbine gas flow or effective turbine nozzle area about 10 percent. At

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1. Engines, Turbojet (3.1.3)
2. Turbines, Axial-Flow (3.7.1.1)

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